REFERENCE 7d

F. ABBEY, "MANUAL OF CRITICALITY DATA, PART 3," AHSB(S) HANDBOOK 5, UKAEA HEALTH AND SAFETY BRANCH (1967).

AHSB (S) HANDBOOK 5

United Kingdom Atomic Energy Authority

HANDBOOK OF EXPERIMENTAL CRITICALITY DATA

PART III - Chapters 7 to 10

1968

AUTHORITY HEALTH AND SAFETY BRANCH

RISLEY, WARRINGTON, LANCASHIRE

HANDBOOK OF EXPERIMENTAL CRITICALITY DATA

PART III*

Compiled by

F. Abbey Safeguards Division

Any comments or suggestions for further data to be included in this handbook should be addressed to:

J. H. Chalmers,
Criticality Inspectorate,
Authority Health and Safety Branch,
Risley, Near Warrington,
Lancashire.

*Parts I and II (published previously)

U.D.C. Nos.
539.175.2
621.039.513

ACKNOWLEDGEMENTS

The compiler is indebted to all those who have contributed to making available the data assembled in the handbook. In addition to the bibliographic references special thanks are due to A.F. Thomas and R.C. Lane of Aldermaston and J.C. Smith of Dounreay for providing details of hitherto unpublished measurements and to Dr. A.D. Callihan, Editor of Nuclear Science and Engineering, Dr. H.C. Paxton of Los Alamos, and the USAEC for permission to reproduce a number of diagrams and photographs.

Part of the work of assembling Chapters 1, 3 and 5 was accomplished by J.H. Chalmers and R.A. O'Sullivan of the Criticality Inspectorate and much assistance has been given throughout by members of the Theoretical and Computing and Editorial Sections.

PREFACE

The literature of critical size measurements is extensive and can be confusing, the same measurement may be reported in a number of places and there may sometimes be variation in detail in the different accounts. Access to papers and reports can also be difficult and will depend on the library facilities available. To establish what measurements have been made in a particular area of interest, and to find detailed and authoritative accounts of the measurements can, therefore, be a time-consuming exercise. Nevertheless this material is the basic data of criticality and the criticality specialist must have recourse to it from time to time. For instance, he may need to check a calculational method and any associated nuclear data against reference experiments or a particular criticality clearance may depend on a detailed comparison of parameters.

It was felt, therefore, that a need existed for a compilation of data in relatively detailed form reference to which could take the place, at least in the first instance, of reference to the original literature. It is hoped that the present handbook which is to be published in three parts, goes at least some way to meeting this need.

In compiling the handbook reference has been made, wherever possible, to the primary account of the critical measurements reported and assemblies are described in as close approximation as possible to the actual assemblies on which measurements were made, (thus, subsequent shape changes, homogenisation etc., have been ignored). This is not to say however, that later accounts of an experiment have not sometimes provided useful additional information. Many excellent review articles and handbooks already exist in the criticality field, providing generalised guidance and data correlations for more or less simplified systems. It is in no way the aim of this handbook to replace these: rather it is to supplement them for the criticality specialist by collecting and assimilating into tabular form, convenient for quick reference, the detailed results on which they are founded and on which similar correlations can be based in the future.

It is intended that the handbook should include only data for systems which are relatively 'clean' and where it is clear that the measurements were sufficiently painstaking and the system was carried close enough to critical for the result to be accurate. With this proviso it is believed that the handbook is reasonably comprehensive so far as material generally available up to about the beginning of the 1964 Geneva Conference is concerned.

Perhaps the most difficult problem in compiling the handbook has been the allocation of the data into tables, determining the length and complexity of the tables. Generally the allocations have been made as a compromise between a desire to associate results for comparable and related systems and the need to avoid tables which are so complex as to be difficult to read.

CONTENTS

INTRODUCTION TO THE TABLES

The Skeleton contents page given at the front of the handbook is supplemented at the beginning of each chapter by a separate contents page showing the organisation of the chapter and listing the tables the chapter contains. Tables are identified by a title and additionally by a two part number of which the first part denotes the chapter in which the table appears and the second part the position of the table in the chapter. Also, as a further aid to rapid reference, each page of the tables carries a 'page-title' in the top left hand corner briefly summarising the type of system to which that chapter or part-chapter refers, (i.e. the degree of heterogeneity - single units, interacting arrays or latticed systems; the nature of the fissile nuclide; the nature of any moderating nuclide; and, in the case of U^{235} systems, whether the uranium is of high (> 90%) or lower enrichment).

Separate compilations of bibliographic references are given for each chapter and follow immediately after the chapter contents pages.

To facilitate easy understanding of the tables a standard form of table layout has been adopted, so far as possible, and an attempt has been made to ensure that each Table is self-contained. As exceptions to these rules information common to all (or nearly all) of the entries in a table is usually brought to the head of the table in note form, thus reducing the complexity of the Table layout, and material compositions and densities are omitted where the materials concerned are commonly-occurring and feature in a large number of Tables. The following compositions in densities may be used for these commonly-occurring materials:

Type 304 Stainless Steel -

(American Iron and Steel Institute Designation); 18·0-20·0 wt% Cr, 8·0-12·0 wt% Ni, 2·0 wt% (max) Mn, 1·0 wt% (max) Si; density 7·9 gm/cc

Type 347 Stainless Steel -

(American Iron and Steel Institute Designation); 17·0-19·0 wt% Cr, 9·0-13·0 wt% Ni, 2·0 wt% (max) Mn, 1·0 wt% max Si; density 7·93 gm/cc

Type 2S Aluminium -

(US Aluminium Assoc. Designation, now renamed Type 1100); 99·0 % aluminium (min.)

Type 3S Aluminium -

(US Aluminium Assoc. Designation, now renamed Type 3003); 1·2 wt% Mn

Zircaloy -

(Westinghouse Designation); zirconium with 1·20-1·70 % Sn; density 6·57 gm/cc

Lucite, Plexiglas or Perspex -

Polymethyl methacrylate plastics, atomic composition $C_5H_8O_2$, density 1·18 gm/cc

Polyethylene -

Atomic composition CH_2, density 0·92 gm/cc

Paraffin Wax -

Atomic composition CH_2, density approx. 0·9 gm/cc

Boric acid -

Atomic composition H_3BO_3

Only numerical values actually provided by the authors of a measurement have been entered in the standard form of Table and, in consequence, there are omissions in certain Tables. These can usually be filled, by interpolation in surrounding data. For instance, aqueous solutions of uranium are sometimes characterised only by the H/U atomic ratio. The specific gravity, uranium content, etc., can, however, be derived by comparison with similar solutions used in other experiments.

Information which has been generally excluded from the Tables includes:

(a) temperature of the assembly, provided this is near ambient

(b) detailed isotopic analysis of fissile materials

(c) detailed analysis of materials of construction, etc., for trace impurities except where significant quantities of neutron poisons are found.

Notes appended to the Tables have been phrased so far as possible in the words of the authors of the measurements referred to. Generally the notes contain information which may be thought:

(a) to extend the usefulness of the measurements (e.g., a number of subcritical observations are included under this heading), or

(b) to bear on the validity of the results (e.g., where available, the values of corrections for unavoidable experimental perturbations from ideal conditions, such as incidental neutron reflection from room walls are given).

Where corrections for experimental conditions are not given it may be assumed that suitable corrections have already been applied to the quoted result. If this is not the case, or is believed not to be the case, appropriate comment is made.

The following terminology and abbreviations are used:

Water - unless qualified this refers to ordinary light water

Mixture - unless qualified this means a mixture which is effectively homogeneous

O.D. - outer diameter

I.D. - inner diameter.

Where the information required to fill a space in a table is not available this is indicated by placing a dash - in the space.

(Note: as will be clear from an examination of the Tables an empty space in a Table implies repetition of the data for the preceeding entry in the Table. This is a device sometimes used to improve the legibility of the sentence).

CHAPTER 7 - SINGLE U^{233} CORES

CHAPTER 7 - CONTENTS

CHAPTER 7 - REFERENCES

1. HANSEN, G.E. Status of Computational and Experimental Correlations for Los Alamos Fast Neutron Critical Assemblies, in Physics of Fast and Intermediate Reactors, IAEA, Vienna (1962)

2. LASSMANN, E.A., and WOOD, D.P. Critical Reflector Thicknesses for spherical U^{233} and Pu^{239} Systems, Nucl. Sci. Eng., 8: 615-620 (1960)

3. PAXTON, H.C. Los Alamos Critical Mass Data, USAEC Report LAMS-3067, Los Alamos Scientific Laboratory, May 6th, 1964

4. FOX, J.K., GILLEY, L.W., and ROHNER, E.R. Critical Mass Studies Part VIII, Aqueous Solutions of U^{233}, USAEC Report ORNL-2143, Oak Ridge National Laboratory, September, 23rd, 1959

5. THOMAS, J.T., FOX, J.K., and CALLIHAN, A.D. A Direct Comparison of Some Nuclear Properties of U^{233} and U^{235}, USAEC Report ORNL-1992; Oak Ridge National Laboratory, December 12th, 1955

6. THOMAS, J.T., FOX, J.K., and CALLIHAN, A.D. A Direct Comparison of Some Nuclear Properties of U^{233} and U^{235}, Nucl. Sci. Eng., 1, 20-32 (1956)

7. GIVIN, R., and MAGNUSON, D.W. The Measurement of Eta and Other Nuclear Properties of U^{233} and U^{235} in Critical Aqueous Solutions, Nucl. Sci. Eng., 12: 364-379 (1962)

8. GIVIN, R., and MAGNUSON, D.W. Critical Experiments for Reactor Physics Studies, USAEC Report ORNL CF 60-4-12, Oak Ridge National Laboratory, 1960

9. FOX, J.K., GIVIN, R., GILLEY, L.W., and MAGNUSON, D.W. Critical Parameters of U^{235} and U^{233} Solutions in Simple Geometry, in Neutron Physics Division Annual Progress Report for Period Ending September 1st, 1959, USAEC Report ORNL-2842, pp 76-77, Oak Ridge National Laboratory, Nov. 16th, 1959

10. THOMAS, J.T., and FOX, J.K. Measurement of y for U^{233}, in USAEC Report ORNL 1715, Oak Ridge National Laboratory.

EXPERIMENTAL RESULTS FOR SINGLE UNMODERATED U^{233} CORES

Table 7.1

Spheres of Uranium Metal

CORE				REFLECTOR			DELAYED CRITICAL U^{233} MASS (kgm)	REFERENCES
Isotopic composition of Uranium (wt%)			Average Density (gm/cc)	Material	Thickness (in.)	Average Density (gm/cc)		
U^{233}	U^{234}	U^{238}						
98·2	1·2	0·6	18·45	←Unreflected→			16·09	1
98·2	1·1	0·7	18·62	Natural Uranium	0·906	18·92	9·84	2
98·2[a]	1·1[a]	0·7[a]	18·62		2·090	18·92	7·47	2
98·7[a]	0·5[a]	0·8[a]	18·42		7·86	19·0	5·63	3
98·2	1·1	0·7	18·62	Beryllium (98wt%)	0·805	1·83	9·84	2
					1·652	1·83	7·47	2
98·2	1·1	0·7	18·62	Tungsten Alloy (91·3wt%)	0·960	-	9·84	2
					2·280	-	7·47	2

a. Isotopic composition for one hemisphere only

Table 7.2

Unreflected Spheres of Aqueous UO_2F_2 Solution

Spheres : Type 35 aluminium; solution feed and drain lines connected at top and bottom

The solution concentrations and critical masses measured in these experiments are said to be about 2% high because of a systematic error

SPHERE WALL THICKNESS (cm)	ISOTOPIC COMPOSITION OF URANIUM (wt%)				SPECIFIC GRAVITY OF SOLUTION	SOLUTION CONCENTRATION (gm U^{233}/litre)	H/U^{233} ATOMIC RATIO	DELAYED CRITICAL PARAMETERS			REFERENCES
	U^{233}	U^{234}	U^{235}	U^{238}				Diameter (cm)	Volume (litre)	U^{233} Mass (kgm)	
-	98·7	0·50	0·01	0·79	1·079	67	381	31·9 (12·6 in.)	16·98[a]	1·14[a]	4
0·127	98·7	-	-	-	-	67·37	381·0	32·0	17·020	1·146	5, 6

a. 40 cc void above the critical solution

Table 7.3

Unreflected Spheres of Aqueous $UO_2(NO_3)_2$ Solution (Includes Solutions with Added Boron)

References: 7, 8, 16

Fissile Solutions : Contained small amounts of thorium and excess nitric acid
Boron added as boric acid

Sphere : Aluminium

ISOTOPIC COMPOSITION OF URANIUM (wt%)				SPECIFIC GRAVITY OF SOLUTION	SOLUTION CONCENTRATION (gm/gm OF SOLUTION)				H/U^{233} ATOMIC RATIO	N/U^{233} ATOMIC RATIO	B/U^{233} ATOMIC RATIO	DELAYED CRITICAL PARAMETERS		
U^{233}	U^{234}	U^{235}	U^{238}		Uranium	Thorium	Total Nitrate ION NO_3^-	Boron				Diameter (in.)	Volume	Mass
Un-poisoned Solutions														
97·70	1·62	0·04	0·64	1·0226	0·01676	0·000074	0·0119	NIL	1533	-	NIL	27·24	-	-
97·67	1·54	0·03	0·76	1·0153	0·01305	0·000056	0·0076	NIL	1986	-	NIL	48·04	-	-
Boron Poisoned Solutions														
97·70	1·62	0·04	0·64	1·0286	0·01927	0·000065	0·0136	0·0000887	1324	-	-	27·24	-	-
				1·0275	0·01867	0·000083	0·0132	0·0000670	1368	-	-		-	-
				1·0274	0·01803	0·000080	0·0128	0·0000453	1417	-	-		-	-
				1·0253	0·01742	0·000077	0·0123	0·0000233	1470	-	-		-	-

Table 7.4

Spheres of Aqueous UO_2F_2 Solution with Water Reflector
(Includes Systems at Elevated Temperatures)

Spheres: Type 35 aluminium; solution feed and drain lines connected at top and bottom.

SPHERE WALL-THICKNESS	CORE							REFLECTOR THICKNESS (cm)	DELAYED CRITICAL CORE PARAMETERS				REFERENCES
	Isotopic Composition of Uranium (wt%)				Specific Gravity of Solution	Solution Concentration (gm U^{233}/litre)	H/U^{233} Atomic Ratio		Diameter (cm)	Volume (litres)	U^{233} Mass (kgm)	Temperature (°C)	
	U^{233}	U^{234}	U^{235}	U^{238}									
0·127 cm	98·7	-	-	-	-	61·34[a]	418·3	> 15	26·4[a]	9·666	0·591	32·0	5, 6, 10
						61·89[a]	414·6		a	9·675	0·596	39·5	5, 6, 10
						64·05[a]	400·5		a	9·704	0·6110	65·5	5, 6, 10
						65·84[a]	389·6		a	9·723	0·6230	83·2	5, 6, 10
						67·80[a]	378·1		a	9·737	0·6380	96·5	5, 6, 10
-	98·7	0·50	0·01	0·79	1·071	61	419	Eff Inf	26·6 (10·4 in)	9·62[b]	0·59[b]	-	4
					1·063	0·039[c]	663[c]		31·9 (12·6 in)	17·02	0·66[c]	-	4
0·127 cm	98·7	-	-	-	-	38·75[a,c]	663·1[c]	> 15	32·0[a]	17·020	0·6590[c]	26·3	5, 6, 10
						39·97[a,c]	643·1[c]		a	17·042	0·6730[c]	56·0	5, 6, 10
						42·65[a,c]	602·8[c]		a	17·074	0·7030[c]	99·5	5, 6, 10

a. Measured at 25°C

b. 40 cc void above critical solution

c. Concentration and masses measured with these spheres are said to be about 2% high because of a systematic error

Table 7.5

Spheres of Aqueous $UO_2(NO_3)_2$ Solution with Water Reflector

Reference : 4

Fissile Solution : Contained a small amount of excess nitric acid

Spheres : Type 35 aluminium; connected to solution storage at top and bottom by flexible tubing

Reflector : Effectively infinite thickness

CORE								DELAYED CRITICAL CORE PARAMETERS		
Isotopic Composition of Uranium (wt%)				Specific Gravity of Solution	Solution Concentration (gm U^{233}/litre)	H/U^{233} Atomic Ratio	N/U^{233} Atomic Ratio	Diameter (cm)	Volume (litre)	U^{233} Mass (kgm)
U^{233}	U^{234}	U^{235}	U^{238}							
98·7	0·50	0·01	0·79	1·087	62	405	2·66	26·6 (10·4 in.)	9·66	0·60

Table 7.6

Unreflected Cylinders of Aqueous UO_2F_2 Solution

Reference : 4

Cylinder : Type 35 aluminium; solution feed and drain lines connected at top and bottom; approximately equilateral in shape

ISOTOPIC COMPOSITION OF URANIUM (wt%)				SPECIFIC GRAVITY OF SOLUTION	SOLUTION CONCENTRATION (gm U^{233}/litre)	H/U^{233} ATOMIC RATIO	DELAYED CRITICAL PARAMETERS				
U^{233}	U^{234}	U^{235}	U^{238}				Diameter (cm)	Solution Height (cm)	Height/Diameter	Volume (litre)	U^{233} Mass (kgm)
98·7	0·50	0·01	0·79	1·198	165	154	25·5 (10·0 in.)	24·0	-	12·22	2·02

Table 7.7

Unreflected Cylinders of Aqueous $UO_2(NO_3)_2$ Solution

Reference : 7, 8, 9

Fissile Solutions : Contained small amounts of thorium and excess nitric acid

Cylinder : Stainless steel

The critical height values given in the Table include a correction of 0·53 in. for the bottom structure.

ISOTOPIC COMPOSITION OF URANIUM (wt%)				SPECIFIC GRAVITY OF SOLUTION	SOLUTION CONCENTRATION (gm/gm of solution)			H/U^{233} ATOMIC RATIO	N/U^{233} ATOMIC RATIO	DELAYED CRITICAL PARAMETERS				
U^{233}	U^{234}	U^{235}	U^{238}		Uranium	Thorium	Total Nitrate ION, NO_3			Diameter (in.)	Solution Height (in.)	Height Diameter	Volume	U^{233} Mass
97·37	1·50	0·04	1·09	1·0203	0·01421	0·000014	0·0083	1819	-	60·92	20·02	-	-	-
97·35	1·52	0·05	1·08	1·0198	0·01362	0·000012	0·0086	1900	-		23·85	-	-	-
97·30	1·49	0·05	1·16	1·0169	0·01300	0·000014	0·0081	1996	-		31·12	-	-	-
97·25	1·55	0·05	1·16	1·0166	0·01233	0·000098	0·0081	2106	-		55·18	-	-	-

Table 7.8

Cylinders of Aqueous UO_2F_2 Solution with Hydrogenous Reflectors

Reference : 4

Isotopic composition of uranium (wt%) : 98·7 U^{233}, 0·50 U^{234}, 0·01 U^{235}, 0·79 U^{238}

Cylinders : Type 35 aluminium; solution feed and drain lines connected at top and bottom; cylinders less than 6·7 in. in dia. were 36 in. high whereas the larger dia. cylinders were approximately equilateral.

Reflectors : Effectively infinite thickness.

CORE		DELAYED CRITICAL CORE PARAMETERS					
Specific Gravity of Solution	Solution Concentration (gms U^{233}/litre)	H/U^{233} Atomic Ratio	Diameter (cm)	Solution Height (cm)	Height/ Diameter	Volume (litre)	U^{233} Mass (kgm)
Water Reflected Cylinders							
1·059	49	522	25·5 (10·0 in.)	25·9±0·1	-	13·18±0·05	0·65±0·05
Paraffin Reflected Cylinders							
1·801	684	34·2	11·2 (4·5 in.)	> 29·9[a,b]	-	> 2·95[a,b]	2·02[a,b]
1·707	600	39·4		> 34·9[a,b]	-	> 3·43[a,b]	2·07[a,b]
1·604	519	45·9		> 42·6[a,b]	-	> 4·19[a,b]	2·18[a,b]
1·530	451	53·7		> 49·0[a,b]	-	> 4·82[a,b]	2·18[a,b]
1·388	332	74·1		> 68·5[a,b]	-	> 6·76[a,b]	2·24[a,b]
1·801	684	34·2	12·7 (5·0 in.)	38±2[c]	-[c]	4·8±0·25[c]	3·3±0·2[c]
1·707	600	39·4		41±2[c]	-[c]	5·1±0·25[c]	3·1±0·2[c]
1·604	519	45·9		41±1[c]	-[c]	5·2±0·1[c]	2·7±0·1[c]
1·388	332	74·1		56·5[c]	-[c]	7·1[c]	2·36[c]
1·388	332	74·1	15·1 (6·0 in.)	24·0[c,d]	-[c,d]	4·31[c,d]	1·43[c,d]
-	-	154	19·1 (7·5 in.)	18·4	-	5·25	0·87
-	-	250	20·5 (48·0 in.)	20·2±0·05	-	6·66±0·02	0·68±0·02
1·090	78	329	21·5 (8·5 in.)	22·2±0·1	-	8·04±·04	0·63±0·05
1·075	65	396	22·9 (9·0 in.)	23·1±0·1	-	9·47±0·04	0·61±0·05
1·035	33	775	30·5 (12·0 in.)	30·5	-	22·28	0·74

a. Cylinder coated internally with a thin layer of M & T chemicals incorporated unichrome to reduce corrosion. This is a plastic material containing 30 wt% chlorine

b. Believed not to be critical at any height

c. No reflector on top surface of core

d. Cylinder coated with unichrome (see note b), masses said to be ~ 2% high as a result

Table 7.9

Cylinders of Aqueous $UO_2(NO_3)_2$ Solution with Hydrogenous Reflectors

Reference: 4

Isotopic composition of uranium (wt%): 98·7 U^{233}, 0·50 U^{234}, 0·01 U^{235}, 0·79 U^{238}

Cylinders: Type 35 aluminium; solution feed and drain lines connected at top and bottom; cylinders less than 6·7 in. in dia. were 36 in. high whereas larger dia. cylinders were approximately equilateral.

Reflectors: Effectively infinite thickness.

CORE				DELAYED CRITICAL CORE PARAMETERS				
Specific Gravity of Solution	Solution Concentration (gm U^{233}/litre)	H/U^{233} Atomic Ratio	N/U^{233} Atomic Ratio	Diameter (cm)	Solution Height (cm)	Height/ Diameter	Volume (litres)	U^{233} Mass (kgm)
Water Reflected Cylinders								
1·069	49	514	2·66	25·5 (10.0 in.)	25·5	-	13·0	0·64
Paraffin Reflected Cylinders								
1·543	381	57·5	2·66	12·7 (5·0 in.)	> 51[a]	-	> 6·40[a]	57·5[a]
1·480	336	67·0	2·66		> 59[a]	-	> 7·40[a]	67·0[a]
1·394	275	84·4	2·66		> 61[a]	-	> 7·65[a]	84·4[a]
1·238	167	145	2·66		> 55	-	> 6·90[a]	1·45[a]
1·543	381	57·5	2·66	15·1 (6·0 in.)	27·9[b]	-[b]	5·00[b]	1·91[b]
1·480	336	67·0	2·66		29·0[b]	-[b]	5·20[b]	1·75[b]
1·394	275	84·4	2·66		30·7[b]	-[b]	5·50[b]	1·51[b]
1·287	198	120	2·66		38·5[b]	-[b]	6·9 [b]	1·37[b]
1·232	160	151	2·66		46·8[b]	-[b]	8·4 [b]	1·34[b]
1·185	127	193	2·66		73±2[b]	-[b]	13·0±0·4[b]	1·63±0·08[b]
1·543	381	57·5	2·66	19·1 (7·5 in.)	16·3	-	4·65	1·77
1·480	336	67·0	2·66		16·2	-	4·60	1·55
1·238	167	145	2·66		18·6	-	5·30	0·89
1·697	490	42·2	2·66	20·5 (8·0 in.)	16·1	-	5·30	2·6
1·543	381	57·5	2·66		14·4	-	4·75	1·81
1·394	275	84·4	2·66		14·7	-	4·85	1·33
1·287	198	120	2·66		16·4	-	5·40	1·07
1·238	167	145	2·66		16·7	-	5·51	0·92
1·232	160	151	2·66		16·7	-	5·51	0·88
1·185	127	193	2·66		18·8	-	6·20	0·79
1·165	117	213	2·66		19·3	-	6·37	0·75
1·145	101	247	2·66		21·2	-	7·0	0·70

Table 7.9 (Cont.)

CORE				DELAYED CRITICAL CORE PARAMETERS				
Specific Gravity of Solution	Solution Concentration (gm U^{233}/litre)	H/U^{233} Atomic Ratio	N/U^{233} Atomic Ratio	Diameter (cm)	Solution Height (cm)	Height/ Diameter	Volume (litres)	U^{233} Mass (kgm)
Paraffin Reflected Cylinders								
1·145	101	247	2·66	21·5 (8·5 in.)	19·4	-	7·00	0·70
1·121	84	297	2·66		21·5	-	7·78	0·65
1·101	10	356	2·66	22·9 (9·0 in.)	21·3	-	8·75	0·62
1·093	67	379	2·66		22·9	-	9·39	0·62
1·090	63	394	2·66	25·5 (10 in.)	19·3	-	9·82	0·63
1·077	55	461	2·66		22·5	-	11·45	0·63
1·069	49	514	2·66		25·2	-	12·9	0·63
1·061	44	582	2·66	30·5 (12·0 in.)	21·1	-	15·40	0·68
1·056	40	630	2·66		23·8	-	17·40	0·70
1·046	33	757	2·66		30·4	-	22·20	0·75

a. Believed not to be critical at any height

b. No reflector on the top surface of the core

CHAPTER 8 - SINGLE CORES OF MIXED FISSILE ISOTOPES

CHAPTER 8 - CONTENTS

CHAPTER 8 - REFERENCES

1. PAXTON, H. C. Los Alamos Critical Mass Data, USAEC Report LAMS-3067, Los Alamos Scientific Laboratory, May 6, 1964

2. PLASSMAN, E. A. and WOOD, D. P. Critical Reflector Thicknesses for Spherical U^{233} and Pu^{239} Systems, Nucl. Sci. Eng. 8:615-620 (1960)

3. BARTON, D. M., BERNARD, W. and HANSEN, G. E. Critical Masses of Composites of Oy and Pu-239-240 in Flat top Geometry, USAEC Report LAMS-2489, Los Alamos Scientific Laboratory, April 12, 1961.

Table 8.1

Unreflected Metal Spheres

These experiments were performed with a sphere of plutonium enclosed in a close-fitting, spherical shell of highly enriched uranium (average density 18·8 gm/cc). The systems shown in the Table were delayed critical

PLUTONIUM SPHERE			URANIUM SHELL			References
Pu^{240} Content (wt %)	Average Density (gm/cc)	Mass (kgm)	Enrichment (wt %)	Thickness (in.)	U^{235} Mass (kgm)	
4·7	19·22	$2{\cdot}52_7$	93·17	1·651	26·8	1
1·5	15·62	$2{\cdot}02_4$[a]	93·17	1·938	36·35	1
4·7	15·60	$2{\cdot}02_2$[a]	93·17	1·948	36·7	1
1·5	15·56	5·72[a]	93·18	1·006	18·8	1
4·9	15·62	8·386[a, b]	93·17	0·652	12·64	2

a. Plutonium contains ~ 1·0 wt % gallium

b. Sphere made up of two hemispheres

Table 8.2

Metal Spheres with Natural Uranium Reflector

Reference: 3

These experiments were performed with a solid, nickel-plated sphere of plutonium enclosed in a shell of highly enriched (93·2 wt %) uranium and then in a natural uranium reflector of fixed outer diameter. The uranium components used were:

(a) Two pairs of identical hemispheres containing most of the highly enriched uranium (8642 gm and 728 gm respectively) and fitting closely round the plutonium sphere

(b) An outer reflector shell containing most of the natural uranium and divided into one hemisphere and two quarter-spheres

(c) A thin shell fitting between (a) and (b). This was subdivided into a number of elements, each of which was available in both highly enriched and natural uranium. Total mass of highly enriched elements 1,092 gm

Further details of these various components and of the plutonium spheres used are given in the Table and in Figure 8.1. Criticality was achieved by replacing natural uranium elements in shell (c) by highly enriched uranium.

PLUTONIUM SPHERE						TOTAL MASS OF HIGHLY ENRICHED URANIUM IN THE SYSTEM (kgm)	REACTIVITY
Isotopic Composition (% By Atoms)				Mass			
Pu^{239}	Pu^{240}	Pu^{241}	Pu^{242}	Plutonium (kgm)	Nickel (gm)		
97·56	2·34	0·10	-	1·61545	10·89	9·530	Δk = 3 cents. Interpolation using the results of the measurements with the next sphere gives a mass of 9521 gm highly enriched uranium corresponding to delayed critical
94·97	4·73	0·30	-	1·61030	11·76	9·755 9·915	Delayed critical Δk ~ 53·8 cents
80·47	16·1	2·92	0·51	1·61119	14·10	10·618	Delayed critical. Obtained by extrapolation of reciprocal multiplication curve

Table 8.3

Metal Cylinders

Reference : 1

These experiments were performed with a cylinder of plutonium (~ 6 wt % Pu^{240}, ~ 1·0 wt % gallium) enclosed in a close-fitting cylindrical shell of highly enriched uranium (93·2 wt % enrichment) and then approximately centrally in a cylindrical reflector of natural uranium external dimensions 18·0 in. dia x 10 in., (average density 19·0 gm/cc). The plutonium components were clad in 0·005 in. thick nickel and contained a 0·06 cu in. central source cavity for which no corrections were made. The dimensions of the shell of highly enriched uranium were such that the height/diameter ratio for the internal and external surfaces was identical. The systems shown in the Table were delayed critical.

PLUTONIUM CYLINDER				U^{235} SHELL		
Average Density (gm/cc)	Diameter (in.)	Height (in.)	Height/Diameter	Mass (kgm)	Average Density (gm/cc)	U^{235} Mass (kgm)
14·83	2·235	2·231	1·00	2·13	18·58	9·7
14·98	4·315	0·875	0·20	3·14	18·66	13·0
15·29	4·315	1·290	0·30	4·73	18·30	5·3 ± 0·2

EXPERIMENTAL RESULTS FOR SINGLE MIXED U^{235}/U^{233} CORES

Table 8.4

Unreflected Metal Spheres

These experiments were performed with a sphere of U^{233} enclosed in a spherical shell of highly enriched U^{235} (average density 18•8 gm/cc). The systems shown in the Table were delayed critical.

U^{233} SPHERE					U^{235} SHELL			REFERENCES
Isotopic Composition (wt %)			Average Density (gm/cc)	U^{233} Mass (kgm)	Enrichment (wt %)	Thickness (in.)	U^{235} Mass (kgm)	
U^{233}	U^{234}	U^{238}						
98•9	0•9	0•2	18•35	2•371	93•17	1•896	34•8	1
98•2	1•1	0•7	18•62	7•47	93•16	0•780	13•77	2
98•2	1•1	0•7	18•62	9•84	93•30	0•478	8•58	2

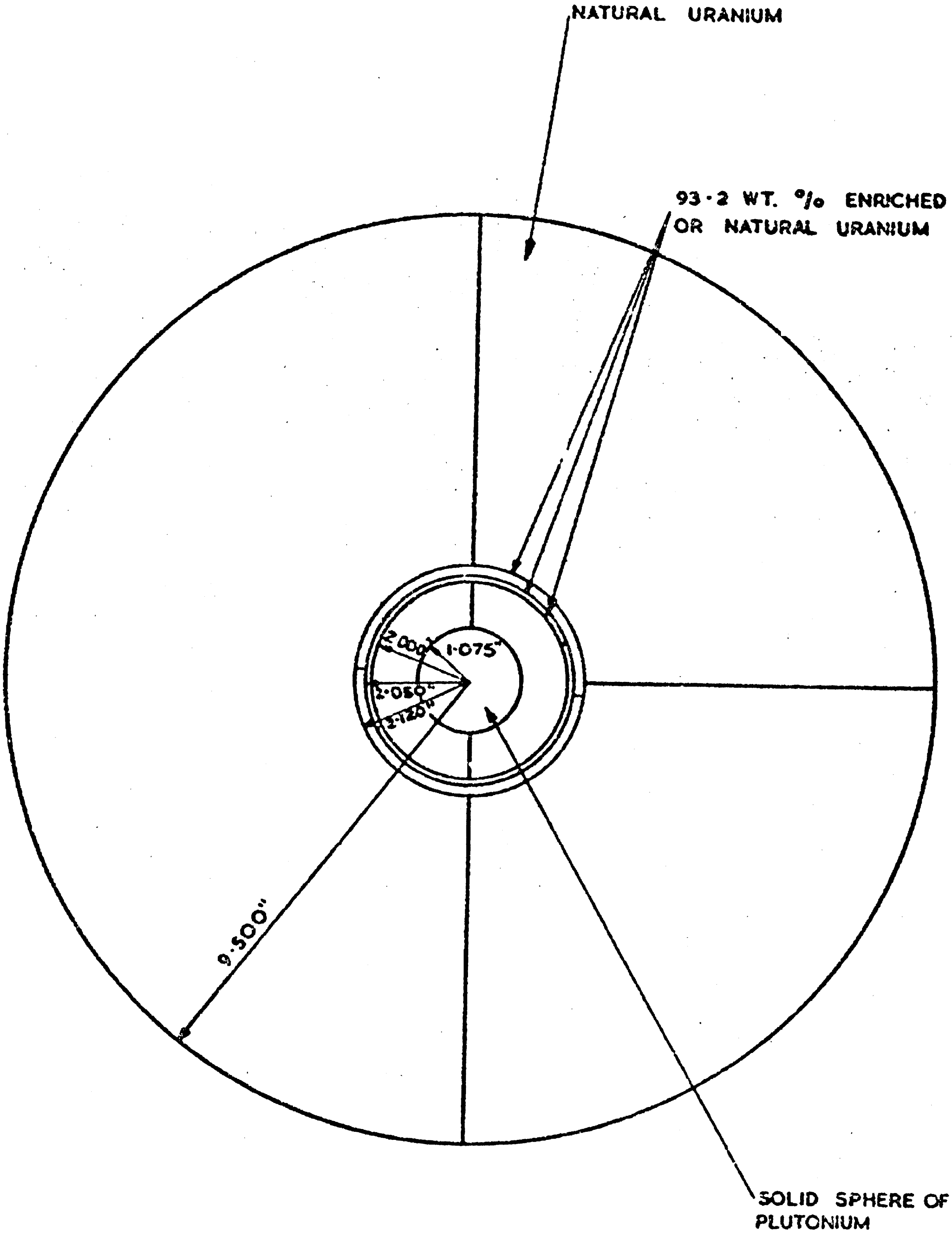


FIG. 8·1 (SEE TABLE 8·2)

CHAPTER 9 - INTERACTING ARRAYS

CHAPTER 9 - CONTENTS

CHAPTER 9 - REFERENCES

1. HOOGTERP, J. C. Critical Masses of Oralloy Lattices Immersed in Water, U.S.A.E.C. Report LA-2026, Los Alamos Scientific Laboratory, November, 1955

2. THOMAS, J. T. Critical Three-Dimensional Arrays of Neutron Interacting Units, Part II - U(93·2) Metal, U.S.A.E.C. Report ORNL-TM-868, Oak Ridge National Laboratory, June, 1964

3. THOMAS, J. T. Critical Arrays of U(93·2) Metal Cylinders, in Neutron Physics Division Annual Progress Report for Period Ending August 1, 1963, U.S.A.E.C. Report ORNL 3499, pp 62-63, Oak Ridge National Laboratory, December, 1963

4. MIHALCZO, J. T. Prompt-Neutron Decay Properties and Critical Dimensions of Unmoderated Cylindrical U(93·2) Metal Assemblies with Large Gaps, Ibid pp 64-67

5. MIHALCZO, J. T. Prompt-Neutron Decay in a Two-Component Enriched Uranium Metal Critical Assembly, U.S.A.E.C. Report ORNL-TM-470, Oak Ridge National Laboratory, Jan 11, 1963

6. MIHALCZO, J. T. Prompt-Neutron Decay in a Two-Component Enriched-Uranium-Metal Critical Assembly, Trans. Am. Nucl. Soc., 6 (1) : 60 (1963)

7. MIHALCZO, J. T. Prompt-Neutron Decay Constants for Unmoderated Uranium Metal Critical Assemblies with Large Gaps, in Neutron Physics Division Annual Progress Report for Period Ending September 1, 1962, U.S.A.E.C. Report ORNL-3360, pp 39-40, Oak Ridge National Laboratory, Jan 11, 1963

8. MIHALCZO, J. T. and LYNN, J. J. Multiplication Measurements with Highly Enriched Uranium Metal Slabs, U.S.A.E.C. Report ORNL-CF-59-7-87, Oak Ridge National Laboratory, July 27, 1959

9. MIHALCZO, J. T. and LYNN, J. J. Multiplication Measurements with Slabs of Enriched Uranium, in Neutron Physics Divison Annual Progress Report for Period Ending September 1, 1959, U.S.A.E.C. Report ORNL-2842, pp 67-68, Oak Ridge National Laboratory, Nov. 16, 1959

10. MIHALCZO, J. T. and LYNN, J. J. Multiplication Measurements with Slabs of Enriched Uranium, Trans. Am. Nucl. Soc. 2 (2) : 80 (1959)

11. MIHALCZO, J. T. and LYNN, J. J. Neutron Multiplication Experiments with Enriched Uranium Metal in Slab Geometry, U.S.A.E.C. Report ORNL-CF-61-4-33, Oak Ridge National Laboratory, 1961

12. FOX, J. K., MIHALCZO, J. T. and GILLEY, L. W. Critical Experiments with 2·09% U^{235} U.S.A.E.C. Report ORNL CF-58-8-3, Oak Ridge National Laboratory, 1958

13. FOX, J. K., MIHALCZO, J. T. and GILLEY, L. W. Critical Experiments with 2·09% U^{235} Enriched Uranium Metal Plates in Water, in Neutron Physics Division Annual Progress Report for Period Ending September, 1st 1958, U.S.A.E.C. Report ORNL-2609, pp 37-38, Oak Ridge National Laboratory, Oct. 28, 1958

14. NEELEY, V. I., LLOYD, R. C. and CLAYTON, E. D. Neutron Multiplication Measurements with Pu-Al Alloy Rods in Light Water, U.S.A.E.C. Report HW-70944, Hanford Atomic Products Operation, Aug. 29, 1961

15. NEELEY, V. I., LLOYD, R. C. and CLAYTON, E. D. Neutron Multiplication Measurements with Pu-Al Alloy Rods in Light Water, In Nuclear Physics Research Quarterly Report of January, February, March 1960, U.S.A.E.C. Report HW-64866, pp 137-142, Hanford Atomic Products Operation, April 20, 1960

16. GILLEY, L. W., CRONIN, D. F., FOX, J. K. and THOMAS, J. T. Critical Arrays of Neutron-Interacting Units, in Neutron Physics Division Annual Progress Report for Period Ending September 1, 1961, U.S.A.E.C. Report ORNL-3193, pp 159-167, Oak Ridge National Laboratory, Oct. 31, 1961

17. FOX, J. K., GILLEY, L. W. and CALLIHAN, D. Critical Mass Studies, Part IX, Aqueous U^{235} Solution, U.S.A.E.C. Report ORNL-2367, Oak Ridge National Laboratory, Mar 4, 1958

18. U.S.A.E.C. Report ORNL CF-55-12-16

19. FOX, J. K. and GILLEY, L. W. Critical Experiments with Aqueous Solutions of U^{235}, in Applied Nuclear Physics Division Annual Report for Period Ending September 10, 1956, U.S.A.E.C. Report ORNL-2081, pp 61-68, Oak Ridge National Laboratory, Nov 5, 1956

20. CALLIHAN, D., CRONIN, D. F., FOX, J. K., MACKLIN, R. L. and MORFITT, J. W. Critical Mass Studies, Part IV, U.S.A.E.C. Report K-406, K-25 Plant, Carbide and Carbon Chemicals Corp., Nov. 28, 1949

21. FOX, J. K. and GILLEY, L. W. Critical Parameters of Unreflected Arrays of Interacting Cylinders Containing Aqueous Solutions of U^{235}, in Neutron Physics Division Annual Progress Report for Period Ending September 1, 1959, U.S.A.E.C. Report, ORNL-2842, pp 82-85, Oak Ridge National Laboratory, Nov. 16, 1959

22. FOX, J. K. and GILLEY, L. W. Critical Parameters of Aqueous Solutions of U^{235}, in Neutron Physics Division Annual Progress Report for Period Ending September 1, 1957, U.S.A.E.C. Report ORNL-2389, pp 71-83, Oak Ridge National Laboratory, Oct. 18, 1957

23. KAMAEV, A. V., DUBOVSKII, B. G., VAVILOV, V. V., POPOV, G. A., PALAMARCHUK, YU. D., and IVANOV, S. P. Experimental Investigation of Effects of Interaction of Two Subcritical Reactors, translated from a publication of the State Committee of the Council of Ministers of the U.S.S.R. for the Utilisation of Atomic Energy, Moscow, 1960, U.S.A.E.C. Report AEC-tr-4708, Division of Technical Information Extension, Oak Ridge, Tenn.

24. FOX, J. K., THOMAS, J. T. and GILLEY, L. W. Unpublished Data, 1961. Also personal communication to J. G. Walford, Dounreay Experimental Reactor Establishment, U.K.A.E.A., 1961

25. THOMAS, J. T. Critical Three-Dimensional Arrays of Neutron Interacting Units, U.S.A.E.C. Report ORNL-TM-719, Oak Ridge National Laboratory, Oct. 1, 1963

26. THOMAS, J. T. and FOX, J. K. Critical Cubic Arrays of Neutron Interacting Units of Aqueous Uranyl Nitrate Solution, in Neutron Physics Division Annual Report for Period Ending September 1, 1962, p. 37, U.S.A.E.C. Report ORNL 3360, Oak Ridge National Laboratory, Jan. 11, 1963

27. THOMAS, J. T. Studies of Critical Cubic Arrays of Fissile Materials, Trans. Am. Nucl. Soc., 6(1) : 169 (1963)

28. FOX, J. K. and GILLEY, L. W. Preliminary Report of Critical Experiments in Slab Geometry, U.S.A.E.C. Report ORNL-CF-56-7-148, Oak Ridge National Laboratory, July 30, 1956

29. FOX, J. K. and GILLEY, L. W. Some Studies of Water Styrofoam and Plexiglas Reflectors, U.S.A.E.C. Report ORNL-CF-58-9-39, Oak Ridge National Laboratory, 1958

30. FOX, J. K. and GILLEY, L. W. Some Studies of Water, Styrofoam and Plexiglas Reflectors, In Neutron Physics Division Annual Progress Report for Period Ending September, 1, 1958, pp 38-40, U.S.A.E.C. Report ORNL-2609, Oak Ridge National Laboratory, Oct. 16, 1958.

31. BINNS, K. C. U.K.A.E.A., Unpublished results

32. U.K.A.E.A., Internal Document

33. LANE, R. C. Measurements of the Critical Parameters of Under-Moderated Uranium-Hydrogen Mixtures at the Intermediate Enrichments, in Criticality Control of Fissile Materials IAEA Stockholm, 1966

34. LANE, R. C. and PERKINS, O. J. E. U.K.A.E.A., Internal Document

35. SCOTT, J. M. U.K.A.E.A., Unpublished results

36. SCOTT, J. M. U.K.A.E.A., Unpublished results

37. HACK, R. C. U.K.A.E.A., Unpublished results

38. WALFORD, J. G., and SMITH, J. C. U.K.A.E.A., Unpublished results.

Table 9.1

Two 20·960 Kgm Cylindrical Units Embedded in Hydrogenous Material

Reference	:	2
Uranium	:	Enrichment 93·2 wt. % Density 18·76 gm/cc
Cylinder dimensions	:	11·506 cm. dia. x 10·765 cm
Array Reflector	:	Polyethylene, at least 15·2 cm thick and close-fitting

The cylinders used in these experiments were supported, with axes vertical and plane surfaces facing, on stainless steel rods passing through two 0·508 cm holes in each cylinder parallel to the axis and located 8·547 cm apart on a diameter. The vertical separations were established by spacers of appropriate length out from Inconel[a] tubing closely fitting the support rods

CYLINDER CONTAINERS	DELAYED CRITICAL SPACING
Each cylinder centred in Plexiglas box, wall thickness 0·64 cm external dimensions 12·9 cm x 12·9 cm (base) x 12·1 cm (height), and corner voids filled with paraffin	12·9 cm between cylinder surfaces with an air cavity between the Plexiglas containers. 10·9 cm between cylinder surfaces when the cavity between the Plexiglas containers is filled with further Plexiglas.
As earlier experiments but Plexiglas containers completely enclosed in 0·06 cm thick cadmium.	Array neutron multiplication less than 2 with containers in contact
As earlier experiments but cadmium replaced by 1·3 cm thick Foamglas[b]	Array neutron multiplication less than 2 with containers in contact
As earlier experiments but Foamglas[b] thickness 2·5 cm	Array neutron multiplication less than 2 with containers in contact
Each cylinder centred in ASA Schedule 40 iron pipe, 0·66 cm wall thickness, 14·1 cm O.D. x 13·2 cm height, provided with 0·66 cm thick end plates	Array 86 cents supercritical with 2·2 cm between cylinder surfaces, i.e., iron containers in contact Array 12 cents supercritical with 0·64 cm thick Plexiglas separating the iron containers

a. Composition 14-17 wt.% Cr, 6-11 wt.% Fe, Balance Ni(+Co) + minor constituents; density 8·51 gm/cc

b. Foamglas is an insulating material of porous borosilicate glass, boron content 2%, density 0·141 gm/cc

EXPERIMENTAL RESULTS FOR U^{235} METAL ARRAYS - HIGHLY ENRICHED

Table 9.2

Three Dimensional Rectilinear Lattices of Cylindrical Units - Air Spaced

Uranium : Enrichment 93·2 wt.%
Density 18·76 gm/cc

Array Reflector : Paraffin, located at the outer boundary of the peripheral lattice cells

The cylinders used in these experiments were supported, with their axes vertical, on stainless steel rods passing through two 0·508 cm dia holes in each cylinder parallel to the axis and located 8·547 cm, apart on a diameter. The vertical separation of the cylinders was established by spacers of appropriate length cut from Inconel [a] tubing closely fitting the support rods. The rods were mounted in sections of aluminium Unistrut attached to the two parts of a split table.

CYLINDERS				ARRAY REFLECTOR		DELAYED CRITICAL PARAMETERS		REFERENCES
Diameter (cm)	Height (cm)	Height to Diameter Ratio	Mass (kgm)	Thickness (cm)	Density (gm/cc)	No. of Cylinders [b]	Surface to Surface Spacing of Cylinders (cm)	
~ 10·5 kgm Cylinders								
11·506	5·387	0·47	10·480	Unreflected		8,(2x2x2)	0 [c]	2
				1·3	0·88		0·23	2
				3·8	0·93		1·98	2
				7·6	0·93		3·42	2
				15·2	0·93		3·70	2
				Unreflected		16,(2x2x4)	1·35	2
11·509	5·382		10·484	Unreflected		27,(3x3x3)	2·007	2
				Unreflected			11·509 (centre to centre spacing)	2
				1·3	0·88		2·992	2
				3·8	0·93		5·872	2
				7·6	0·93		8·258	2
				15·2	0·93		8·689	2
11·494	5·382		10·458	Unreflected		45,(3x3x5)	3·442	2
11·481	5·382		10·434	Unreflected		64,(4x4x4)	3·952	2
				15·2	0·93		12·360	2
9·116	8·641	0·95	10·507	Unreflected		8,(2x2x2)	0 [e]	2
				1·3	0·88		0·602	2
				3·8	0·93		2·362	2
				7·6	0·93		3·970	2
				15·2	0·93		4·308	2
9·116	8·641		10·489	Unreflected		27,(3x3x3)	2·436	2
				1·3	0·88		3·426	2
				3·8	0·93		6·579	2
				7·6	0·93		9·017	2
				15·2	0·93		9·434	2

Table 9.2 (Cont.)

CYLINDERS				ARRAY REFLECTOR		DELAYED CRITICAL PARAMETERS		REFERENCES
Diameter (cm)	Height (cm)	Height to Diameter Ratio	Mass (kgm)	Thickness (cm)	Density (gm/cc)	No. of Cylinders [b]	Surface to Surface Spacing of Cylinders (cm)	
~ 15·5 Kgm Cylinders								
11·494	8·077	0·70	15·692	Unreflected		8,(2x2x2)	0·902	2
				Unreflected			11·494 (centre to centre spacing)	2
				1·3	0·88		1·905	2
				3·8	0·93		4·961	2
				7·6	0·93		7·391	2
				15·2	0·93		7·823	2
11·490	8·077		15·683	Unreflected		27,(3x3x3)	4·204	2
				1·3	0·88		5·677	2
				3·8	0·93		10·190	2
				7·6	0·93		13·693	2
				15·2	0·93		14·194	2
~ 21 Kgm Cylinders								
11·464	10·765	0·94	20·805	Unreflected		8,(2x2x2)	2·217 [g]	2,3
11·506	10·765		20·960	Unreflected			2·248	2,3
				Unreflected			13·503 (centre to centre spacing)	2
				1·3	0·88		3·678	2,3
				2·5	0·93		5·710	2,3
				3·8	0·93		8·207	2,3
				7·6	0·93		11·509	2,3
				15·2	0·93		11·986	2,3
				15·2	0·93		5·398 [h]	2,3
11·488	10·765	0·94	20·896	Unreflected		8,(2x4x1)	1·062 [i]	2
						9,(3x3x1)	0·658	2
						16,(2x2x4)	3·907	2
						16,(2x4x2)	3·891	2
						16,(4x4x1)	1·516	2
						18,(3x3x2)	4·641	2

Table 9.2 (Cont'd)

URANIUM CYLINDERS				ARRAY REFLECTOR		DELAYED CRITICAL PARAMETERS		REFERENCES
Diameter (cm)	Height (cm)	Height to Diameter Ratio	Mass (kgm)	Thickness (cm)	Density (gm/cc)	No. of[b] Cylinders	Surface to Surface Spacing of Cylinders (cm)	
11·484	10·765	0·94	20·877	Unreflected		27,(3x3x3)	6·363[j]	2,3
				Unreflected			17·602 (centre to centre spacing)	2
				1·3	0·88		8·574	2,3
				3·8	0·93		14·764	2,3
				7·6	0·93		18·720	2,3
				15·2	0·93		19·147	2,3
				15·2	0·93		10·541[k]	2,3
9·116	17·282	1·90	21·008	Unreflected		8,(2x2x2)	1·466	2
				15·2	0·93		10·328	2
~26 kgm Cylinders								
11·509	13·459	1·17	26·218	Unreflected		8,(2x2x2)	3·543[g]	2,3
				Unreflected			15·778 (centre to centre spacing)	2
				1·3	0·88		5·423	2,3
				3·8	0·93		11·532	2,3
				7·6	0·93		15·697	2,3
				15·2	0·93		16·378	2,3
11·486	13·459		26·113	Unreflected		27,(3x3x3)	8·494	2,3
				1·3	0·88		11·323	2,3
				3·8	0·93		19·606	2,3
				7·6	0·93		24·498	2,3
				15·2	0·93		24·991	2,3

a. Composition 14–17 wt % Cr, 6–11 wt % Fe, Balance Ni(+Co) + Minor constituents; density 8·51 gm/cc

b. The numbers in parentheses are the horizontal and vertical dimensions, respectively, of the array expressed in number of cylinders

c. Array was subcritical with an apparent neutron source multiplication of ~ 3

d. Array subcritical, maximum apparent source neutron multiplication ~ 70

e. Array was subcritical with an apparent neutron source multiplication of ~ 10

f. Array subcritical, maximum apparent source neutron multiplication ~ 81

g. A composite array formed by bringing together one half of each of these arrays along a common centre line until their lattice cell boundaries coincided was more than 1 dollar subcritical with apparent source neutron multiplication of ~ 5

h. 'Corner' reflection only by 76·2 x 76·2 can base reflector and two 76·2 x 45·7 side reflectors

i. This array consisted of two clusters of four touching cylinders. The dimension quoted is the separation between the two clusters

j. Replacing the central cylinder of this array by a 11·486 cm dia. x 13·459 cm cylinder, mass 26·113 kgm produced a reactivity increase in excess of 1·50 dollars

k. 'Corner' reflection only by 106·7 x 106·7 can base reflector and two 106·7 x 76·2 cm side reflectors

Table 9.3

Three Dimensional Rectilinear Lattices of 20·960 kgm Cylindrical Units Separated by Plexiglas Sheet

Uranium	: Enrichment 93·2 wt.% Density 18·76 gm/cc.
Cylinder dimensions	: 11·506 cm dia x 10·765 cm
Array Reflector	: Paraffin, located at the outer boundary of the peripheral lattice cells

The cylinders used in these experiments were each centered in a Plexiglas box, the dimensions of which are given in the Table. The cylinders and enclosing boxes were supported, with the cylinder axes vertical, on stainless steel rods passing through two 0·508 cm dia holes in each cylinder parallel to the axis and located 8·547 cm. apart on a diameter. The vertical separations were established by spacers of appropriate length cut from Inconel [a] tubing closely fitting the support rods. The rods were mounted in sections of aluminium Unistrut attached to the two parts of a split table.

PLEXIGLAS BOXES			ARRAY REFLECTOR		DELAYED CRITICAL PARAMETERS		REFERENCES
Wall Thickness (cm)	Outside Dimensions (cm) Base	Height	Thickness (cm)	Density (gm/cc)	No. of Cylinders	Surface to Surface Spacing of Cylinders (cm)	
0·64	12·9 x 12·9	12·1	Unreflected		8,(2x2x2)	4·082	2
			15·2	0·93		12·662	2
0·64	15·6 x 15·6	14·8	Unreflected		8,(2x2x2)	4·239	2,3
			1·3	0·88		5·875	2,3
			7·6	0·93		12·573	2,3
			15·2	0·93		12·929	2,3
1·27	17·9 x 17·9	17·2	Unreflected		8,(2x2x2)	6·619	2,3
			1·3	0·88		8·611	2,3
			15·2	0·93		14·503	2,3
2·38	21·4 x 21·4	20·7	Unreflected		8,(2x2x2)	10·239	2
			15·2	0·93		16·477	2
			Unreflected		27,(3x3x3)	16·289 [de]	2
None			Unreflected		8,(2x2x2)	3·239 [f]	2,3
0·64	15·6 x 15·6	14·8	Unreflected		8,(2x2x2)	5·169 [f]	2,3

a Composition 14–17 wt.% Cr, Balance Ni(+Co) + Minor constituents; density 8·51 gm/cc
b The numbers in parentheses are the horizontal and vertical dimensions, respectively, of the array expressed in number of cylinders
c A Plexiglas sheet 41·6 x 43·2 x 0·16 cm inserted vertically in the midplane of this array caused a 1·7 per cent decrease in reactivity
d Cylinder dimensions 11·484 cm dia x 10·765 cm mass 20·877 kgm
e Replacement of the central container in this array by a Plexiglas box having 2·54 cm. thick walls and outside dimensions of 22·4 x 22·4 (base) x 21·6 (height) cm resulted in a decrease in reactivity of about 5 cents. A Plexiglas sheet 68·6 x 76·2 x 0·32 cm inserted vertically midway between adjacent containers increased the reactivity by 5·6 cents
f Each cylinder centered in a primary container of 5" ASA Schedule 40 iron pipe, 0·66 cm wall thickness, 14·1 cm o.d. x 13·2 cm height, provided with end plates of thickness equal to the pipe wall.

Table 9.4

Cubic Lattices of ½ in., 1 in. Cubic Units in Water

Reference: 1

These experiments were performed in a 35½ in. dia. x 28 in. tank filled to within 5 in. of the top with water. An effectively infinite thickness of water is said to have been maintained on all sides of the array. The uranium cubes were supported on Lucite trays and the outer boundary of the array was maintained as near to a cube as the number of units assembled would allow.

URANIUM CUBES				DELAYED CRITICAL PARAMETERS	
Enrichment (wt. %)	Size	Density (gm/cc)	Average Mass (gm)	No. of Cubes	Centre to Centre Spacing of Cubes (in.)
94·52	½ in.	18·72	38·35	469·36	0·75
				378·10	1·00
				371·58	1·17
				367·67	1·30[a]
				521·51	1·50
				1434	2·25
94·3	1 in.	18·72	306·8	83·44	1·25
				74·97	1·50
				73·01	1·75
				79·86	2·00

a. Body centred cubic lattice

Table 9.5

Square Lattices of $\frac{1}{8}$ in. dia. x 12 in. Rods in Water

Reference : 1
Uranium : Enrichment, 93·614 wt.%
Density, 18·72 gm/cc
Average mass of uranium per rod : 44·561 gm

(The lengths of the rods were varied in the range 12 $\pm \frac{1}{8}$ in. in an attempt to obtain a uniform mass per rod. However, five rods had diameters of 0·123 in. and averaged 42·34 gm).

These experiments were performed in a $35\frac{1}{2}$ in. dia. x 28 in. tank filled to within 5 in. of the top with water. An effectively infinite thickness of water is said to have been maintained on all sides of the array.

The uranium rods were supported in Lucite matrix plates and the outer boundary of the array was maintained approximately circular.

DELAYED CRITICAL PARAMETERS	
No. of Rods	Centre to Centre Spacing of Rods (in.)
171	0·500
149	0·625
152	0·750
173	0·875
203	1·000

Table 9.6

Two Discs with Plane Surfaces Facing

Reference : 4

Uranium : Enrichment 93·2 wt.%
Density 18·7 gm/cc

Array Reflector : All arrays air-spaced and unreflected

DELAYED CRITICAL PARAMETERS	
Surface to Surface Spacing of Discs (in.)	Thickness of Discs (in.)
7 in. dia. Discs	
0·125	2·625
0·24	2·75
0·35	2·875
0·46	3·00
0·6	3·10
0·76	3·25
11 in. dia. Discs	
0·125	1·75
0·44	1·80
0·78	2·00
1·02	2·10
1·60	2·25
2·00	2·30
2·60	2·50
3·25	2·60
4·00	2·75
5·00	2·875
6·50	3·00
9·00	3·10
15 in. dia. Discs	
0·475	1·625
1·00	1·75
1·60	1·80
2·25	2·00
2·90	2·10
3·80	2·25
4·85	2·35
6·1	2·50

Table 9.7

Two 8 in. x 10 in. Slab-Shaped Units with Larger Surfaces Facing

References : 5, 6, 7

Uranium : Enrichment 93·2 wt.%
Density 18·72 gm/cc

Array Reflector : All arrays air-spaced and unreflected

The references give two sets of results, an 'as measured' set and a corrected set. The corrections were determined experimentally and take into account the effects of an aluminium column supporting the lower of the two slabs and a 0·024 in. thick stainless steel diaphragm supporting the upper slab. No account, is taken, however, of the reflection of neutrons by the walls and floor of the room

DELAYED CRITICAL PARAMETERS		
Surface to Surface Spacing of Slabs		Thickness of Slabs (in.)
Measured (in.)	Corrected for Effects of Support Structures (in.)	
-	0·000	1·812
0·170	0·113	1·875
0·443	0·384	2·000
0·705	0·638	2·125
1·013	0·935	2·250
1·347	1·258	2·375
2·153	2·038	2·625
2·668	2·531	2·750
3·302	3·142	2·875
4·102	3·880	3·000
5·175	4·902	3·125

Table 9.8

Cubic Lattices of 8 in. x 10 in. x 1 in. Slab-Shaped Units

Mass of U^{235} per slab : 22·9 kgm

These arrays were assembled by bolting each slab, enclosed in a 0·005 in. thick plastic bag, into a 1/16 in. thick aluminium tray. The trays were then assembled horizontally, and with the slabs oriented with corresponding dimensions parallel, into a steel framework attached to a 1 in. thick steel table. A further 1/32 in. thick sheet of aluminium was then suspended below each position in the lattice, (see Figure 9.1)

Reflection to the base of the array was provided by the steel table and the remaining sides were reflected by a 1 in. thickness of Plexiglas. The shape of the array, as defined by the centres of the peripheral slabs, was maintained as near a cube as the number of slabs assembled would allow and the steel/Plexiglas reflector was located at the outer boundary of the peripheral lattice cells.

URANIUM ENRICHMENT (wt.%)	MATERIALS SEPARATING THE SLABS	DELAYED CRITICAL PARAMETERS		REFERENCES
		No. of Slabs	Centre of Centre Spacing of Slabs (in.)	
93·4	Air-spaced	145	11	8, 9, 10
93·4		185 ± 10	12	8, 9, 10
93·4		350 ± 30	15	8, 9, 10
93·15	1 in. thickness of Plexiglas situated midway between the slabs in all three co-ordinate planes	2·2	2	11
93·15		3·65	3	11
93·4		27	11	8, 9, 10
		36 + 5 − 2	12	8, 9, 10
93·4		75 + 5 − 2	15	8, 9, 10
93·4	1 in. thickness of Plexiglas situated midway between the slabs in all three co-ordinate planes, plus Styrafoam [a]. Filling 70% of the lattice cell volume	36 + 5 − 2	12	8, 9, 10
93·4	As earlier experiment but Styrafoam replaced by Foamglas [b]	185 ± 130	12	8, 9, 10

a. Atomic composition CH, density 0·024 gm/cc

b. Foamglas, an insulating material, is a porous borosilicate glass, boron content - 2%, density 0·141 gm/cc.

Table 9.9

Plane Rectilinear Lattices of 30 in. x $3\frac{1}{8}$ in. x $\frac{1}{4}$ in. Plates of 2·09 wt.% Enriched Uranium in Water

References : 12, 13

Mass of uranium per plate : 7·09 kgm

The plates used in these experiments were copper-plated and varnished to prevent oxidation.

The lattices were assembled by laying the plates face-downwards in parallel layers of four on a Plexiglas table. Separation within and between the layers was maintained by Plexiglas spacers, giving a volume fraction of Plexiglas of about 0·20. When the last row contained fewer than four plates these were centred in the row if possible.

In order to prevent trapping of air in the assembly the lattice was tilted up at one end. This resulted in a non-uniform top reflector. An effectively infinite thickness of water is said to have been maintained on the remaining sides of the array. If the total number of plates in each of these assemblies is reduced by one half plate in the top row the resulting system was found to be subcritical with an effectively infinite water reflector on all sides.

THICKNESS OF TOP REFLECTOR (SEE NOTES PREFACING TABLE) (cm)	DELAYED CRITICAL PARAMETERS		
	No. of Plates	Surface to Surface Spacing of Plates (in.)	
		Within Rows	Between Rows
5·2 - 8·7	54	0	$\frac{5}{8}$
6·5 - 9·4	49		$\frac{3}{4}$
7·0 - 10·0	47		$\frac{7}{8}$
21·1 - 25·3	48		1
13·0 - 16·2	51		$1\frac{1}{8}$
4·8 - 7·8	$45\frac{1}{2}$	$\frac{1}{4}$	$\frac{7}{8}$
5·1 - 8·1	$45\frac{1}{2}$	$\frac{3}{8}$	$\frac{7}{8}$
6·0 - 9·0	47	$\frac{5}{8}$	$\frac{7}{8}$

EXPERIMENTAL RESULTS FOR ARRAYS OF HYDROGEN MODERATED U^{235} UNITS - HIGHLY ENRICHED

Table 9.10

Linear Arrays of Cylindrical Units - Air Spaced

TYPE OF[a] CYLINDER	FISSILE SOLUTION: Fissile Material	FISSILE SOLUTION: Uranium Enrichment (wt.%)	FISSILE SOLUTION: Specific Gravity of Solution	FISSILE SOLUTION: Solution Concentration (gm U^{235}/litre)	FISSILE SOLUTION: H/U^{235} Atomic Ratio	ARRAY REFLECTOR	DELAYED CRITICAL PARAMETERS: No. of Cylinders	DELAYED CRITICAL PARAMETERS: Spacing Between Exterior Surfaces Of Cylinders	DELAYED CRITICAL PARAMETERS: Solution Height Above Common Base	REFERENCES
$5\frac{3}{8}$ in. dia. Cylinders (OD)										
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	Array against 6 in. thick Plexiglas wall	18 19	Nil Nil	44·25 in. (Not Critical) 41·70 in. in five control units in centre of array 44·25 in. elsewhere	16 16
6 in. dia. Cylinders (ID)										
B	UO_2F_2	93·2	1·661	537·6	44·3	Unreflected	6	0·15 in.	> 35 in.[b,c]	17,18,19
20·32 cm. dia. Units (OD)										
F	$UO_2(NO_3)_2$	92·6	1·55	-	59	Unreflected 15·24 cm thick paraffin reflector located at the outer boundary of the peripheral lattice cells	16 4	Nil[d,e] 3·94 cm[d]	- -	25 25
8 in. dia. Cylinders (ID)										
B	UO_2F_2	93·2	1·661	537·6	44·3	Unreflected	2	0·15 in. 3·0	26·9 in.[b] > 49 in.[b,c]	17,18,19 17,18,19
B	UO_2F_2	93·4	1·566	-	52·9	Unreflected		0·0 in.	> 38 cm[f]	20
B	UO_2F_2	93·2	1·661	537·6	44·3	Unreflected	3	0·15 in. 3·0	18·0 in.[b] 49·44 in.[b,g]	17,18,19 17,18,19
B	UO_2F_2	93·2	1·661	537·6	44·3	Unreflected	4	0·15 in. 3·0 in.	16·5 in.[b] 38·2 in.[b]	17,18,19 17,18,19
B	UO_2F_2	93·2	1·661	537·6	44·3	Unreflected	5	0·15 in. 3·0 in. 15·0 in.	15·8 in.[b] 31 in.[b] > 24 in.[b,c]	17,18,19 17,18,19 17,18,19
$9\frac{1}{2}$ in. dia. Cylinders (ID)										
B	UO_2F_2	93·2	1·109	86·8	297	Unreflected	2	1·0 in. 3·0 in. 6·0 in. 8·0 in.	26·1 in. 31·7 in. 44·5 in. 54·0 in.	21 21 21 21

Table 9.10 (Cont.)

TYPE OF[a] CYLINDER	FISSILE SOLUTION					ARRAY REFLECTOR	DELAYED CRITICAL PARAMETERS			REFERENCES
	Fissile Material	Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio		No. of Cylinders	Spacing Between Exterior Surfaces of Cylinders	Solution Height Above Common Base	
B	UO_2F_2	93·2	1·109	86·8	297	Unreflected	3	2·0 in. 6·0 in. 10·0 in. 15·0 in.	22·3 in. 33·2 in. 43·6 in. 60·1 in.	21 21 21 21
B	UO_2F_2	93·2	1·109	86·8	297	Unreflected	4	3·0 in. 6·0 in. 10·0 in.	22·7 in. 30·0 in. 38·5 in.	21 21 21
B	UO_2F_2	93·2	1·109	86·8	297	Unreflected	5	3·0 in. 6·0 in. 10·0 in.	21·7 in. 28·3 in. 36·2 in.	21 21 21
B	UO_2F_2	93·2	1·109	86·8	297	Unreflected	6	3·0 in. 10·0 in.	21·3 in. 34·8 in.	21 21
10 in. dia. Cylinders (ID)										
B	UO_2F_2	93·2	-	-	49·2 to 50·1	Unreflected	2	0·14 in. 4·14 in. 12·14 in.	10·28 in. 11·94 in. 12·5 in.	22 22 22
B	UO_2F_2	93·4	1·566	-	52·9	Unreflected		0·0 cm	20 cm[f]	20
B	UO_2F_2	93·2	-	-	85·7	Unreflected		0 in. 3·14 in. 6·14 in. 12·14 in.	10·28 in. 11·67 in. 12·22 in. 12·50 in.	22 22 22 22
B	UO_2F_2	93·4	1·187	-	169	Unreflected		0·0 cm 2·0 cm 5·8 cm 9·6 cm 15·6 cm 24·6 cm 33·9 cm 50·0 cm	28·7 cm[f] 30·7 cm[f] 32·8 cm[f] 34·3 cm[f] 35·8 cm[f] 37·2 cm[f] 38·2 cm[f] 39·1 cm[f]	20 20 20 20 20 20 20 20
B	UO_2F_2	93·2	-	-	325	Unreflected		0·14 in. 3·14 in. 9·14 in.	6·94 in. 22·78 in. 30·28 in.	22 22 22
B	UO_2F_2	93·2	-	-	328	Unreflected		6·14 in. 16·14 in.	26·67 in. 35·56 in.	22 22
						Cylinder walls reflected by half shells of water 3½ in. thick (see Fig. 9.2), 4 in. Plexiglas base reflectors		1·25 in. 12·19 in. 27·19 in.	11·69 in. 14·13 in. 14·94 in.	22 22 22
B	UO_2F_2	93·4	1·101	-	329	Unreflected		0·0 cm 1·9 cm 4·8 cm 8·0 cm 16·6 cm 31·3 cm 43·3 cm	40·8 cm[f] 44·9 cm[f] 50·0 cm[f] 54·8 cm[f] 64·7 cm[f] 74·4 cm[f] 80·1 cm[f]	20 20 20 20 20 20 20

Table 9.10 (Cont.)

TYPE OF CYLINDER[a]	FISSILE SOLUTION: Fissile Material	FISSILE SOLUTION: Uranium Enrichment (wt.%)	FISSILE SOLUTION: Specific Gravity of Solution	FISSILE SOLUTION: Solution Concentration (gm U^{235}/litre)	FISSILE SOLUTION: H/U^{235} Atomic Ratio	ARRAY REFLECTOR	DELAYED CRITICAL PARAMETERS: No. of Cylinders	DELAYED CRITICAL PARAMETERS: Spacing Between Exterior Surfaces of Cylinders	DELAYED CRITICAL PARAMETERS: Solution Height Above Common Base	REFERENCES
C	$UO_2(NO_3)_2$	90	-	70	-	Array standing on a graphite stack and against a graphite wall		30 cm	32 cm	23
								5 cm	37 cm	23
								15 cm	44 cm	23
								30 cm	52 cm	23
								60 cm	62 cm	23
								110 cm	70 cm	23
B	UO_2F_2	93·2	-	-	49·2 (Cyl. No.1)) 83·1 (Cyl. No.2))	Unreflected		2·06 in.	11·11 in.	22
								6·14 in.	12·22 in.	22
								12·14 in.	12·80 in.	22
B	UO_2F_2	93·2	-	-	328 (Cyl. No.1)) 50·1 (Cyl. No.2))	Unreflected		0·14 in.	11·39 in.	22
								4·14 in.	12·50 in.	22
								12·14 in.	13·06 in.	22
								18·14 in.	13·19 in.	22
B	UO_2F_2	93·2	-	-	254 (Cyl. No.1)) 328 (Cyl. No.2))	Unreflected		0·14 in.	13·16 in.	22
B	UO_2F_2	93·2	-	-	254 (Cyl. No.1)) 328 (Cyl. No.2))	Unreflected		2·14 in.	19·17 in.	22
30 cm dia Cylinders (ID)										
C	$UO_2(NO_3)_2$	90	-	105	260	Unreflected	2	0 cm	26·5 cm	23
								3 cm	27·9 cm	23
								6 cm	28·7 cm	23
								12 cm	29·6 cm	23
								30 cm	30·8 cm	23
								60 cm	31·2 cm	23
								90 cm	31·3 cm	23
								105 cm	31·5 cm	23
								120 cm	31·5 cm	23
C	$UO_2(NO_3)_2$	90	-	74	380			0 cm	33 cm	23
								7·5 cm	33·4 cm	23
								15 cm	28·2 cm	23
								30 cm	39·5 cm	23
								60 cm	40·8 cm	23
								90 cm	41·2 cm	23
								120 cm	41·3 cm	23
C	$UO_2(NO_3)_2$	90	-	70	-	Array standing on a graphite stack and against a graphite wall		0 cm	23·2 cm	23
								5 cm	25·3 cm	23
								15 cm	27·6 cm	23
								30 cm	29·5 cm	23
								60 cm	30·8 cm	23
								110 cm	31·4 cm	23

Table 9.10 (Cont.)

TYPE OF[a] CYLINDER	FISSILE SOLUTION: Fissile Material	Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	ARRAY REFLECTOR	DELAYED CRITICAL PARAMETERS: No. of Cylinders	Spacing Between Exterior Surfaces of Cylinders	Solution Height Above Common Base	REFERENCES
C	$UO_2(NO_3)_2$	90	-	55	520	Unreflected	2	0 cm 7·5 cm 15 cm 30 cm 60 cm 90 cm 120 cm	41·0 cm 48·8 cm 52·4 cm 56·6 cm 60 cm 61·5 cm 62 cm	23 23 23 23 23 23 23
15 in. dia Cylinders (10)										
B	UO_2F_2	93·4	1·187	-	169	Unreflected	2	0·3 cm 5·0 cm 15·0 cm 50·0 cm	17·3 cm[f] 17·8 cm[f] 18·0 cm[f] 18·3 cm[f]	20 20 20 20
B	UO_2F_2	93·4	1·101	-	329	Unreflected		0·2 cm 5·0 cm 9·7 cm 31·3 cm 50·0 cm	20·1 cm[f] 20·8 cm[f] 21·0 cm[f] 21·3 cm[f] 21·5 cm[f]	20 20 20 20 20
20 in. dia Cylinders (10)										
D	UO_2F_2	93·4	1·187	-	169	Unreflected	2	0·0 cm 5·0 cm 20·0 cm	14·7 cm[f] 14·8 cm[f] 14·8 cm[f]	20 20 20
D	UO_2F_2	93·4	1·187	-	329	Unreflected		0·0 cm 10·0 cm 25·0 cm	16·7 cm[f] 17·0 cm[f] 17·3 cm[f]	20 20 20

(a) The Type A cylinders were a $5\frac{3}{4}$ in. O.D. seamless polyethylene bottle, approximately 48 in. long, which had a $1\frac{1}{2}$ in. dia. capped opening and a nominal capacity of ~ 13 ℓ
The wall thickness varied from 0·45 in. at the bottom to 0·20 in. at the top, resulting in a volume averaged I.D. of ~ 4·67 in.
The Type B cylinders were 1/16 in. thick Type 3S aluminium
The Type C cylinders were 1·5 mm thick stainless steel (18 Cr - 9 Ni - Ti type)
The Type D cylinders were 1/16 in. thick Type 347 stainless steel
The Type F cylinders were 20·32 cm. O.D. x 19·05 cm. external height of 0·635 cm. thick Plexiglas and contained 5·000 ± 0·0003 litres of fissile solution

(b) These experiments were performed inside a $9\frac{1}{2}$ ft. dia. x 10 ft. steel tank. No corrections were made to the results for stray reflection or for the effects of the feed line.

(c) Extrapolation of the reciprocal source-neutron multiplication curve is said to indicate that this array could not be made critical at any solution height.

(d) Total nitrate in the solution corresponded to an N/U^{235} atomic ratio of 2·006. In these experiments the cylinders were held in position on an aluminium unistrut frame by bolted lugs.

(e) Array subcritical with apparent source neutron multiplication of approximately 6.

(f) The fissile solution feed line formed a column of solution 3 in. dia and about 1 ft. long attached to the bottom of the stationary member of each pair of cylinders. An appropriate correction for the effect of this on the critical height of the stationary cylinder in isolation was evaluated experimentally, (1·2 cm. for the 8 in. dia unit, 0·7 cm. for the 10 in. dia unit) and the contribution to interaction was shown to be negligible. The critical heights reported are the average of the actual height in the moveable cylinder and the corrected height in the stationary cylinder.

(g) This height was derived from an extrapolation of reciprocal multiplication curve from an experimental height of 40 in. and is said to be purposely set low. It may be that the system cannot be made critical at any solution height.

EXPERIMENTAL RESULTS FOR ARRAYS OF HYDROGEN MODERATED U^{235} UNITS - HIGHLY ENRICHED

Table 9.11

Linear Arrays of Cylindrical Units in Water

Fissile Material : UO_2F_2

Cylinders : 1/16 in. thick Type 3S aluminium

FISSILE SOLUTION				DELAYED CRITICAL PARAMETERS			REFERENCES
Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	No. of Cylinders	Spacing Between Exterior Surfaces of Cylinders	Solution Height Above Common Base	
5 in. dia Cylinders (ID)							
93·4	1·566	-	52·9	2	0·2 cm	36·4 cm [a]	20
					2·9 cm	51·9 cm [a]	20
					3·3 cm	56·2 cm [a]	20
					3·8 cm	65·3 cm [a]	20
					4·0 cm	70·2 cm [a]	20
					4·2 cm	76 cm [a]	20
93·2	-	-	50·1	6	2·17in.	16·14cm [b]	22
93·2	-	-	50·1	7	0·20in.	9·32in. [b]	22
					1·11in.	11·14in. [b]	22
					2·17in.	16·14in. [b]	22
					3·11in.	36·02in. [b]	22
$5\frac{1}{2}$ in. dia Cylinders (ID)							
93·4	1·926	-	29·9	2	0·5 cm	27·1 cm [a]	20
					2·9 cm	31·0 cm [a]	20
6 in. dia Cylinders (ID)							
93·4	1·926	-	29·9	2	0·1 cm	22·8 cm [a]	22
					2·9 cm	26·9 cm [a]	22
93·2	1·661	537·6	44·3		0·15in.	9·7 in. [b]	12
					3·0 in.	16·3 in. [b]	17
					6·0 in.	24·9 in. [b]	17
					9·0 in.	28·2 in. [b]	17
93·4	1·566	-	52·9		0·0 cm	21·0 cm [a]	20
					2·9 cm	24·0 cm [a]	20
					5·8 cm	31·5 cm [a]	20
					8·7 cm	40·7 cm [a]	20
					11·0 cm	47·6 cm [a]	20
					13·0 cm	52	20
93·4	1·187	-	169		0·4 cm	28·9 cm [a]	20
					2·0 cm	32·5 cm [a]	20
					4·0 cm	42·2 cm [a]	20
					6·0 cm	60·8 cm [a]	20
93·4	1·101	-	329		0·2 cm	63·1 cm [a]	20
					0·5 cm	66·2 cm [a]	20
					0·8 cm	69·8 cm [a]	20

Table 9.11 (Cont.)

FISSILE SOLUTION				DELAYED CRITICAL PARAMETERS			REFERENCES
Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	No. of Cylinders	Spacing Between Exterior Surfaces of Cylinders	Solution Height Above Common Base	
93·2	1·661	537·6	44·3	3	0·15in.	8·1 in.[b]	17
					3·0 in.	14·2 in.[b]	17
					6·0 in.	23·3 in.[b]	17
					9·0 in.	27·8 in.[b]	17
					12·0 in.	28·8 in.[b]	17
93·2	1·661	537·6	44·3	4	0·15in.	7·8 in.[b]	17
					3·0 in.	13·7 in.[b]	17
					6·0 in.	23·0 in.[b]	17
93·2	1·661	537·6	44·3	5	3·0 in.	13·4 in.[b]	17
					9·0 in.	27·0 in.[b]	17
93·2	1·661	537·6	44·3	6	0·15in.	7·4 in.[b]	17
					3·0 in.	13·2 in.[b]	17
					6·0 in.	22·6 in.[b]	17
8 in. dia Cylinders (ID)							
93·4	1·926	-	29·9	2	0·0 cm	13·4 cm[a]	20
					0·4 cm	13·5 cm[a]	20
					1·5 cm	14·0 cm[a]	20
93·2	1·661	537·6	44·3		0·15in.	6·9 in.[b]	17
					3·0 in.	8·3 in.[b]	17
93·4	1·566	-	52·9		0·0 cm	12·8 cm[a]	20
					0·0 cm	13·2 cm[a]	20
					0·8 cm	13·6 cm[a]	20
					1·7 cm	13·9 cm[a]	20
					1·8 cm	13·7 cm[a]	20
					3·5 cm	14·9 cm[a]	20
					3·6 cm	15·3 cm[a]	20
					4·2 cm	15·2 cm[a]	20
					5·7 cm	16·1 cm[a]	20
					6·8 cm	16·6 cm[a]	20
					7·0 cm	17·0 cm[a]	20
					8·6 cm	17·6 cm[a]	20
					10·9 cm	18·4 cm[a]	20
					14·4 cm	18·8 cm[a]	20
					14·7 cm	18·8 cm[a]	20
					14·7 cm	19·1 cm[a]	20
					20·1 cm	18·6 cm[a]	20
					43·0 cm	18·8 cm[a]	20
93·2	1·661	537·6	44·3	3	0·15in.	6·3 in.[b]	17
					3·0 in.	8·2 in.[b]	17
93·2	1·661	537·6	44·3	4	0·15in.	6·2 in.[b]	17
					3·0 in.	8·0 in.[b]	17
93·2	1·661	537·6	44·3	5	0·15in.	6·1 in.[b]	17
					3·0 in.	8·0 in.[b]	17

Table 9.11 (Cont.)

FISSILE SOLUTION				DELAYED CRITICAL PARAMETERS			REFERENCES
Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	No. of Cylinders	Spacing Between Exterior Surfaces of Cylinders	Solution Height above Common Base	
10 in. dia. Cylinders (ID)							
93·4	1·926	-	29·9	2	0·0 cm	11·0 cm[a]	20
93·4	1·566	-	52·9		0·2 cm	10·3 cm[a]	20
					0·3 cm	11·2 cm[a]	20
					7·0 cm	12·2 cm[a]	20
					10·5 cm	12·7 cm[a]	20
					13·0 cm	12·9 cm[a]	20
					20·0 cm	13·0 cm[a]	20
93·4	1·101	-	329		0·0 cm	16·9 cm[a]	20
					3·0 cm	18·7 cm[a]	20
					8·0 cm	21·1 cm[a]	20
15 in. dia. Cylinders (ID)							
93·4	1·566	-	52·9	2	0·0 cm	7·3 cm[a]	20
					2·9 cm	7·6 cm[a]	20
					5·8 cm	7·65 cm[a]	20
					11·6 cm	7·7 cm[a]	20
93·4	1·187	-	169		0·0 cm	9·0 cm[a]	20
					3·0 cm	9·3 cm[a]	20
					22·0 cm	9·7 cm[a]	20
93·4	1·101	-	329		0·0 cm	11·5 cm[a]	20
					5·0 cm	12·3 cm[a]	20
					20·0 cm	12·6 cm[a]	20

a. These experiments were performed inside a water-filled tank measuring 4 ft. 5 in. x 2 ft. 3 in. x 3 ft. 6 in. deep, maintaining at least 10 cm of water on all sides of the array. Small aluminium water tanks, 6 in. deep and fitting snugly into the respective reactors, provided reflectors for the top surface of the fissile solution

The fissile solution feed line formed a column of solution 3 in. in diameter and about 1 ft. long attached to the bottom of the stationary member of each pair of cylinders. An appropriate correction for the effect of this on the critical height of the stationary cylinder in isolation was estimated experimentally, (1·2 cm for the 8 in. dia. unit, 0·7 cm for the 10 in. dia. unit; and the contribution to interaction was shown to be negligible. The critical heights reported are the average of the actual height in the moveable cylinder and the corrected height in the stationary cylinder

b. These experiments were performed inside a $9\frac{1}{2}$ ft. dia. x 10 ft. steel tank which was filled with water to the level of the fissile solution at critical (i.e., the array was without top reflection). No corrections were made to the results for end effects due to the structure of the cylinders or the feed line.

EXPERIMENTAL RESULTS FOR ARRAYS OF HYDROGEN MODERATED U^{235} UNITS – HIGHLY ENRICHED

Table 9.12

Hexagonal Lattices of Cylindrical Units – Air Spaced

Array Reflector : All arrays unreflected

TYPE OF[a] CYLINDER	FISSILE SOLUTION: Fissile Material	Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	DELAYED CRITICAL PARAMETERS: No. of[b] Cylinders	Spacing Between Exterior Surfaces of Cylinders	Solution Height above Common Base	REFERENCES
5 in. Cylinders (ID)									
B		93·2	-	-	50·1	7	0·28 in. 1·17 in.	11·36 in. 16·25 in.	22 22
$5\frac{1}{4}$ in. dia Cylinders (OD)									
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	3	Nil	44·25 in. (Not critical)	16
						4	Nil	34·56 in.	16
						5	Nil	15·70 in.[c]	16
						7	1·55 in.	$44\frac{1}{4}$ in.[d]	16
						19	4·56 in.	$44\frac{1}{4}$ in.[d]	16
6 in. dia Cylinders (ID)									
B	UO_2F_2	93·2	1·661	537·6	44·3	3	0·15 in. 3·0 in.	> 70 in.[e] (Extrapolation from 53 in.) > 27 in.[e,f]	17 17
B	UO_2F_2	93·2	1·661	537·6	44·3	7	0·15 in. 1·0 in. 2·0 in. 3·0 in. 4·0 in. 6·0 in.	8·9 in.[e] 13·0 in.[e] 20·3 in.[e] 33 ±2 in.[e] > 50 in.[e,g] > 27 in.[e,f]	17 17 17 17 17 17
B	$UO_2(NO_3)_2$	92·6	1·55	-	309		0·15 in. 1·00 in. 2·00 in. 2·50 in.	9·76 in. 15·40 in. 27·47 in. 39·16 in.	16 16 15 16
B	UO_2F_2	93·2	1·105	83·6	-		0·3 in. 1·0 in. 2·0 in.	12·2 in. 22·4 in. 77 in. (Extrapolation from 63 in.)	21 21 21
B	$UO_2(NO_3)_2$	92·6	1·55	-	-	19	3·51 in. 4·95 in. 5·94 in. 6·64 in.	20·00 in.[h] 30·00 in.[h] 40·00 in.[h] 50·00 in.[h]	16 16 16
20·32 cm dia Cylinders									
F	$UO_2(NO_3)_2$	92·6	1·55	-	59	19	1·35 cm		25

Table 9.12 (Cont.)

TYPE OF[a] CYLINDER	FISSILE SOLUTION					DELAYED CRITICAL PARAMETERS			REFERENCES
	Fissile Material	Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	No. of[b] Cylinders	Spacing Between Exterior Surfaces of Cylinders	Solution Height above Common Base	
8 in. dia Cylinders (ID)									
B	UO_2F_2	93·2	1·661	537·6	44·3	3	0·15 in.	10·7 in.[e]	17
							1·0 in.	13·8 in.[e]	17
							2·0 in.	17·8 in.[e]	17
							3·0 in.	22·0 in.[e]	17
							4·0 in.	27·1 in.[e]	17
							6·0 in.	42 in.[e]	17
							9·0 in.	> 60 in.[e] (Extrapolated from 39 in.)	17
B	UO_2F_2	93·2	1·105	83·6	309		0·15 in.	16·3 in.	21
							1·0 in.	31·2 in.[j]	21
							2·0 in.	-	21
B	UO_2F_2	93·2	1·661	537·6	44·3	7	0·15 in.	7·2 in.[e]	17
							1·0 in.	8·5 in.[e]	17
							2·0 in.	10·1 in.[e]	17
							3·0 in.	11·7 in.[e]	17
							4·0 in.	13·2 in.[e]	17
							6·0 in.	16·5 in.[e]	17
							9·0 in.	22±2 in.[e]	17
							12·0 in.	> 25 in.[e,k]	17
B	UO_2F_2	93·2	1·105	83·6	309		1·0 in.	11·3 in.	21
							3·0 in.	17·8 in.	21
							6·0 in.	35·4 in.	21
							7·0 in.	46·9 in.	21
$9\frac{1}{2}$ in. dia Cylinders (ID)									
B	UO_2F_2	93·2	1·109	86·8	297	3	1·0 in.	13·4 in.	21
							4·0 in.	20·3 in.	21
							8·0 in.	28·1 in.	21
							12·0 in.	36·3 in.	21
							13·0 in.	49·7 in.	21
							22·0 in.	60·1 in.	21
B	UO_2F_2	93·2	1·109	86·8	297	7	3·0 in.	12·1 in.	21
							10·0 in.	20·1 in.	21
							22·0 in.	32·9 in.	21

Table 9.12 (Cont.)

a. The Type A cylinders were a $5\frac{3}{4}$ in. O.D. polyethylene bottle, approximately 48 ins long which had a $1\frac{1}{2}$ ins capped opening and a nominal capacity of ~ 13 ℓ. The wall thickness, varied from 0·45 in. at the bottom to 0·20 in. at the top, resulting in a volume averaged I.D. of 4·67 in.

The Type B cylinders were 1/16 in. thick Type 3S aluminium.

The Type F cylinders were 20·32 cm O.D. x 19·05 cm external height of 0·635 cm thick Plexiglas and contained 5·000 ± 0·0003 litres of fissile solution.

b. The configuration of these arrays for various numbers of cylinders is illustrated in Figure 9.3.

c. An array of 5 units in contact arranged in the configuration shown in Figure 9·4 was not critical at a solution height of 44·25 ins

d. Each cylinder contained 12·76 litres of Fissile solution

e. These experiments were performed inside a $9\frac{1}{2}$ ft dia x 10 ft steel tank. No corrections were made to the results for stray reflection or for the effects of the feed line.

f. These cylinders were filled to a height of at least 27 ins and the extrapolation of the reciprocal source-neutron multiplication curve is said to indicate that they could not be made critical at any height.

g. Extrapolation of a reciprocal source-neutron multiplication curve from a height of 29 ins is said to show that this system may be critical at a height greater than 50 ins.

h. The 12 outer cylinders were of 6 ins O.D. and 0·05 in. wall thickness

i. Total nitrate in the solution corresponded to an N/U^{235} atomic ratio of 2·006. In these experiments the cylinders were held in position on an aluminium Unistrut frame by bolted lugs.

j. Extrapolation indefinite, said to be probably not critical at any height.

k. Extrapolation of a source neutron multiplication curve from 17 ins is said to indicate that the system may be critical at a height as low as that recorded.

EXPERIMENTAL RESULTS FOR ARRAYS OF HYDROGEN MODERATED U^{235} UNITS - HIGHLY ENRICHED

Table 9.13

Hexagonal Lattices of Cylindrical Units in Water

Fissile Material : UO_2F_2

Cylinders : 1/16 in. thick Type 3S aluminium

These experiments were performed inside a $9\frac{1}{2}$ ft dia x 10 ft steel tank filled with water to the level of the fissile solution at critical, (i.e., the array was without top reflection). No corrections were made to the results for end effects due to the structure of the cylinders of the feed line.

FISSILE SOLUTION				DELAYED CRITICAL PARAMETERS			REFERENCES
Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	No. of[a] Cylinders	Spacing Between Exterior Surfaces of Cylinders (in.)	Solution Height Above Common Base (in.)	
5 in. dia Cylinders (ID)							
93·2	-	-	50·1	7	0·28	5·68	22
					1·11	6·36	22
					2·11	8·41	22
					4·17	15·45	22
6 in. dia Cylinders (ID)							
93·2	1·661	537·6	44·3	3	0·15	7·0	17
					3·0	12·3	17
93·2	1·661	537·6	44·3	7	0·15	5·0	17
					1·0	5·4	17
					2·0	6·9	17
					3·0	9·2	17
					4·0	12·2	17
					6·0	18·8	17
					9·0	25·9	17
					12·0	28·4	17
					15·0	29·7	17
					24·5	28·8	17
8 in. dia Cylinders (ID)							
93·2	1·661	537·6	44·3	3	0·15	5·7	17
					1·0	6·1	17
					2·0	7·0	17
					3·0	7·8	17
					4·0	8·4	17
					6·0	8·9	17
93·2	1·661	537·6	44·3	7	0·15	4·7	17
					1·0	5·0	17
					2·0	5·9	17
					3·0	7·0	17
					4·0	7·8	17
					6·0	8·7	17
					9·0	9·0	17

a. The configuration of these arrays for various numbers of cylinders is illustrated in Figure 9.3

Table 9.14

Hexagonal Lattices of Cadmium-Clad Cylindrical Units - Air Spaced

Reference 17
Fissile Solution : UO_2F_2 at 537·6 gm U^{235}/litre and 93·2 wt.% enrichment Specific Gravity 1·661 H/U^{235} Atomic Ratio 44·3
Cylinders : 1/16 in. thick Type 3S aluminium with 0·028 in. thick cadmium on walls only
Array Reflector : All arrays unreflected

These experiments were performed inside a $9\frac{1}{2}$ ft. dia. x 10 ft. steel tank. No corrections were made to the results for stray reflection or for the effect of the feed line.

DELAYED CRITICAL PARAMETERS		
No. of[a] Cylinders	Spacing Between Exterior Surfaces of Cylinders (in.)	Solution Height Above Common Base (in.)
6 in. dia. Cylinders (ID)		
3	1·0	> 27[b]
7	0·15	10·3
	1·0	15·1
	2·0	24·6
	3·0	> 50[c]
	4·0	> 27[b]
8 in. dia. Cylinders (ID)		
3	0·15	11·7
	1·0	14·6
	2·0	18·5
	3·0	22·9
	4·0	28·2
	5·0	35·2
	6·0	43
	9·0	> 55 (Extrapolated from 39)

Table 9.14 (Cont.)

DELAYED CRITICAL PARAMETERS		
No. of[a] Cylinders	Spacing Between Exterior Surfaces of Cylinders (in.)	Solution Height above Common Base (in.)
7	0·15	7·7
	1·0	9·0
	2·0	10·5
	3·0	12·0
	4·0	13·6
	6·0	16·9
	9·0	> 25[d]

a. The configuration of these arrays for various numbers of cylinders is illustrated in Figure 9.3

b. These cylinders were filled to a height of at least 27 in. and the extrapolation of the reciprocal source-neutron multiplication curve is said to indicate that they could not be made critical at any height

c. Extrapolation of a reciprocal source-neutron multiplication curve from a height of 29 in. is said to show that this system may be critical at a height greater than 50 in.

d. Extrapolation of a source neutron multiplication curve from 17 in. is said to indicate the system may be critical at a height as low as that recorded.

Table 9·15

Hexagonal Lattices of Cadmium - Clad Cylindrical Units in Water

Reference : 17

Fissile Solution : UO_2F_2 at 537·6 gm U^{235}/litre and 93·2 wt.% enrichment
Specific Gravity 1·661
H/U^{235} Atomic Ratio 44·3

Cylinders : 1·16 in. thick Type 3S aluminium with 0·028 in. thick cadmium on walls only

These experiments were performed inside a $9\frac{1}{2}$ ft. dia. x 10 ft. steel tank filled with water to the level of the fissile solution at critical (i.e., the array was without top reflection). No corrections were made to the results for end effects due to the structure of the cylinders or the feed line

DELAYED CRITICAL PARAMETERS		
No. of[a] Cylinders	Spacing Between Exterior Surfaces of Cylinders (in.)	Solution Height Above Common Base (in.)
6 in. dia. Cylinders (ID)		
3	1·0	> 27[b]
7	0·15	8·1
	1·0	7·4
	2·0	> 27[b]
	3·0	> 27[b]
	4·0	> 27[b]
8 in. dia. Cylinders (ID)		
3	0·15	8·4
	1·0	10·8
	2·0	14·2
	3·0	17·1
	4·0	19·5
	6·0	22·1
	9·0	23·5

Table 9.15 (Cont.)

DELAYED CRITICAL PARAMETERS		
No. of[a] Cylinders	Spacing Between Exterior Surfaces of Cylinders (in.)	Solution Height Above Common Base (in.)
7	0·15	6·2
	1·0	8·2
	2·0	11·2
	3·0	14·3
	4·0	17·1
	6·0	21 ± 1
	9·0	20 → 23·5

a. The configuration of these arrays for various numbers of cylinders is illustrated in Figure 9.3

b. These cylinders were filled to a height of at least 27 in. and the extrapolation of the reciprocal source-neutron multiplication curve is said to indicate that they could not be made critical at any height

EXPERIMENTAL RESULTS FOR ARRAYS OF HYDROGEN MODERATED U^{235} UNITS - HIGHLY ENRICHED

Table 9.2[illegible]

Square Lattices of Cylindrical Units - Air Spaced

(See also Table 9.19)

Array Reflector : All arrays unreflected

TYPE OF[a] CYLINDER	FISSILE SOLUTION: Fissile Material	FISSILE SOLUTION: Uranium Enrichment (wt.%)	FISSILE SOLUTION: Specific Gravity of Solution	FISSILE SOLUTION: Solution Concentration (gm U^{235}/litre)	FISSILE SOLUTION: H/U^{235} Atomic Ratio	DELAYED CRITICAL PARAMETERS: No. of[b] Cylinders	DELAYED CRITICAL PARAMETERS: Spacing Between Exterior Surfaces of Cylinders (in.)	DELAYED CRITICAL PARAMETERS: Solution Height Above Common Base (in.)	REFERENCES
$5\frac{3}{8}$ in. Cylinders (OD)									
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	4 (2 x 2)	Nil	44·25 (not critical)	16
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	9 (3 x 3)	1·18	$22\frac{1}{2}$[c]	16
							1·59	$33\frac{3}{8}$[c]	16
							1·75	$44\frac{1}{4}$[c]	16
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	16 (4 x 4)	2·16	$22\frac{1}{2}$[c]	16
							2·89	$33\frac{3}{8}$[c]	16
							3·32	$44\frac{1}{4}$[c]	16
							3·72	$88\frac{1}{2}$[c]	
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	25 (5 x 5)	3·00	$22\frac{1}{2}$[c]	16
							3·92	$33\frac{3}{8}$[c]	16
							4·55	$44\frac{1}{4}$[c]	16
							5·35	$88\frac{1}{2}$[c]	16
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	36 (6 x 6)	3·58 5·64	$22\frac{1}{2}$[c] $44\frac{1}{4}$[c]	16
							5·64	29·03 in. five control units[d] 44·25 in. remaining units	16
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	30 (5 x 6)	5·64	34·67 in. five control units[e] 44·25 in. remaining units	16
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	47 (7 x 7)	8·33	$88\frac{1}{2}$[c]	16

Table 9.16 (Cont.)

TYPE OF[a] CYLINDERS	FISSILE SOLUTION: Chemical Form of Uranium	Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	DELAYED CRITICAL PARAMETERS: No. of[b] Cylinders	Spacing Between Exterior Surfaces of Cylinders (in.)	Solution Height Above Common Base (in.)	REFERENCES
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	64 (8x8)	4·43	$22\frac{1}{2}$[c]	16
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	81 (9x9)	7·79	$44\frac{1}{4}$[c]	16
A	$UO_2(NO_3)_2$	92·6	1·55	-	-	100 (10x10)	5·04	$22\frac{1}{2}$[c]	16
$5\frac{3}{8}$ in. dia Cylinder (OD)									
E	$UO_2(NO_3)_2$	92·6	1·55	-	-	9 (3x3)	1·43	$22\frac{1}{4}$	16
E	$UO_2(NO_3)_2$	92·6	1·55	-	-	16 (4x4)	2·60 2·34	$22\frac{1}{4}$ $22\frac{1}{4}$[f]	16 16
E	$UO_2(NO_3)_2$	92·6	1·55	-	-	24 (3x8)	2·80	$22\frac{1}{4}$	16
E	$UO_2(NO_3)_2$	92·6	1·55	-	-	27 (3x9)	2·82	$22\frac{1}{4}$	16
E	$UO_2(NO_3)_2$	92·6	1·55	-	-	36 (6x6)	4·25	$22\frac{1}{4}$	16
E	$UO_2(NO_3)_2$	92·6	1·55			64 (8x8)	5·32	$22\frac{1}{4}$	16
6 in. dia Cylinders (ID)									
B	$UO_2(NO_3)_2$	92·6	1·55	-	-	4 (2x2)	0·15 0·38	26·33 42·8	16 16
B	$UO_2(NO_3)_2$	92·6	1·55	-	-	9 (3x3)	1·50 1·70 2·30 2·70 3·00	20·26[g] 21·67[h] 30·65[h] 40·01[h] 49·60[h]	16 16 16 16 16
B	$UO_2(NO_3)_2$	92·6	1·55	-	-	16 (4x4)	2·58 3·77 4·50 5·00	20·00[i] 30·00 40·08 50·40	16 16 16 16

Table 9.16 (Cont.)

TYPE[a] OF CYLINDER	FISSILE SOLUTION					DELAYED CRITICAL PARAMETERS			REFERENCES
	Chemical Form of Uranium	Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	No. of[b] Cylinders	Spacing Between Exterior Surfaces of Cylinders (in.)	Solution Height Above Common Base (in.)	
$9\frac{1}{2}$ in. dia. Cylinders (ID)									
B	UO_2F_2	93·2	1·109	86·8	297	4 (2 x 2)	3·0	15·8	21
							10·0	27·2	21
							22·0	47·4	21
							30·0	62·5	21

a. The Type A cylinders were a $5\frac{3}{8}$ in. seamless polyethylene bottle, approximately 48 in. long, which had a $1\frac{1}{2}$ in. dia. capped opening and a nominal capacity of ~ 13 l. The wall thickness varied from 0·45 in. at the bottom to 0·20 in. at the top, resulting in a volume averaged ID of ~ 4·67 in.

The Type B cylinders were $\frac{1}{16}$ in. thick Type B 3S aluminium

The Type E cylinders were a $5\frac{1}{2}$ in. O.D. polyethylene bottle, approximately 48 in. long, which had a wide capped opening, a welded bottom, and a nominal capacity of ~ 15 litres. The walls had a uniform thickness of 0·25 in.

b. The number in parentheses are the dimensions of the array expressed in number of cylinders

c. In these experiments three different solution heights were used - $22\frac{1}{2}$ in., $33\frac{3}{8}$ in., $44\frac{1}{4}$ in., corresponding to 5·90 litres, 9·30 litres, 12·76 litres of fissile solution per cylinder. The height of $88\frac{1}{2}$ in. was obtained by using a double tier of the $44\frac{1}{4}$ in. units, the vertical spacing between solution in the two tiers being 5·6 in.

d. This experiment was performed inside a $9\frac{1}{2}$ ft dia. x 10 ft steel tank

e. This experiment was performed inside a $9\frac{1}{2}$ ft dia. x 10 ft steel tank containing sufficient water to form a bottom reflector for the array

f. Plastic liner 0·20 in. thick inside each cylinder, resulting in a contained volume of 6·33 litres per cylinder

g. Only a central row of three cylinders were as specified. The remaining six cylinders were of 6 in. O.D. and 0·05 in. wall thickness

h. Two diagonally opposed corner cylinders were of 6 in. O.D. and 0·05 in. wall thickness

i. Only one inner row of four cylinders as specified. The remaining six cylinders were of 6 in. O.D. and 0·05 in. wall thickness

Table 9.17

Square Lattices of Cylindrical Units in Water

Reference : 16

Fissile Solution : $UO_2(NO_3)_2$ at 410 gm U/litre and 92·6 wt.% enrichment
Specific Gravity 1·55
H/U^{235} Atomic Ratio

Cylinders : $5\frac{3}{8}$ in. O.D. seamless polyethylene bottles, approximately 48 in. long, which had a $1\frac{1}{2}$ in. dia. capped opening and a nominal capacity of ~ 13 l. The wall thickness varied from 0·45 in. at the bottom to 0·20 in. at the top, resulting in a volume averaged ID of ~ 4·67 in. Each cylinder contained 12·76 litres of fissile solution

These experiments were performed inside a water filled tank measuring $9\frac{1}{2}$ ft in dia. x 10 ft.

DELAYED CRITICAL PARAMETERS		
No. of[a] Cylinders	Spacing Between Exterior Surfaces of Cylinders	Solution Height Above Common Base
36 (6 x 6)	5·64 in.	44·25 in. (not critical)

a. The numbers in parenthesis are the dimensions of the array expressed in number of cylinders

EXPERIMENTAL RESULTS FOR ARRAYS OF HYDROGEN MODERATED U^{235} UNITS - HIGHLY ENRICHED

Table 9.18

Square lattices of Cylindrical Units Separated by Plexiglas Sheet

Reference : 16
Fissile Solution : $UO_2(NO_3)_2$ at 410 gm U/litre and 92·6 wt.% enrichment
Specific Gravity 1·55
H/U^{235} Atomic Ratio
Cylinders : $5\frac{3}{4}$ in. O.D. seamless polythene bottles approximately 48 in. long, which had a $1\frac{1}{2}$ in. dia. capped opening and a nominal capacity of ~ 13 litres. The wall thickness varied from 0·45 in. at the bottom to 0·20 in. at the top, resulting in a volume averaged I.D. of ~ 4·67 in. Each cylinder contained 12·76 litres of fissile solution

These experiments all refer to a basic array of 16 (4 x 4)* cylinders

MATERIALS SEPARATING THE CYLINDERS	ARRAY REFLECTOR				SPACING BETWEEN EXTERIOR SURFACES OF CYLINDERS (in.)
	Material	Geometry	Thickness (in.)	Density	
0·5 in. thick cylindrical shell of Plexiglas surrounding each cylinder	Unreflected				3·72
0·5 in. thickness of Plexiglas situated midway between the cylinders in both coordinate planes	Plexiglas	-	0·25	-	4·94
1·00 in. thickness of Plexiglas situated midway between the cylinders in both coordinate planes	Plexiglas	-	0·5	-	5·39
1·50 in. thickness of Plexiglas situated midway between the cylinders in both coordinate planes	Plexiglas	-	0·75	-	5·26

* The numbers in parenthesis are the dimensions of the array expressed in number of cylinders

Table 9.19

Square Lattices of Cylindrical Units - Array Divided into Two Parts by Concrete or Plexiglas/Water Slab

Reference : 24

Fissile Solution : $UO_2(NO_3)$ at 410 gm uranium/litre and 92·6 wt.% enrichment
Specific Gravity 1·55
H/U^{235} atomic ratio 56

Cylinders : 15·2 cm dia., 1·6 mm thick aluminium

Water Containers : 3·2 mm thick aluminium

The configuration of these arrays is illustrated in Figure 9·5. The majority of cylinders in each array were filled to capacity, i.e., a standard height of 50 in.; the heights recorded in the Table are for the remaining non-standard cylinders.

FIGURE NO.	DELAYED CRITICAL PARAMETERS	
	Spacing Between Exterior Surfaces of Cylinders (in.)	Solution Height Above Common Base in Non-Standard Cylinders (in.)
Air-Spaced Systems		
9·5 (a)	4·4	(54·10 (3 cyls.)) (20·2 (1 cyl.))
9·5 (b)	4·4	(53·10 (6 cyls.)) (20·2 (1 cyl.))
9·5 (c)	4·85 5·0	5 0
9·5 (d)	4·26	-
Concrete[a] -Spaced Systems		
9·5 (e)	4·85	-
9·5 (f)	4·85	28·50
9·5 (g)	4·85	28·88
9·5 (h)	4·85	10
Plexiglas/Water Spaced Systems		
9·5 (j)	4·15	-
9·5 (k)	4·4	-

a. Neutron relaxation length ~ 12 in.

Table 9.20

Three Cylindrical Units at the Vertices of an Isosceles Triangle - Air Spaced

Reference : 17
Fissile Solution : UO_2F_2 at 537·6 gm U^{235}/litre and
93·2 wt.% enrichment
Specific Gravity 1·661
H/U^{235} Atomic Ratio 44·3

Cylinders : 8 in. OD, 1/16 in. thick Type 3S aluminium
Array Reflector : All arrays unreflected

These experiments were performed inside a 9½ ft dia. x 10 ft steel tank. No corrections were made to the results for stray reflection or for the effect of the feed line

DELAYED CRITICAL PARAMETERS		
Spacing Between Exterior Surfaces of Cylinders (See Figure 9·6) (in.)	Vertex Angle α (See Figure 9·6)	Solution Height Above Common Base (in.)
0·15	60^{o} 90^{o} 120^{o}	10·7 14·2 16·7
3·0	45^{o} 60^{o} 90^{o} 120^{o}	16·4 22·0 28·1 34·4

Table 9.21

Three Cylindrical Units at the Vertices of an Isosceles Triangle in Water

Reference : 17

Fissile Solution : UO_2F_2 at 537·6 gm U^{235}/litre and 93·2 wt.% enrichment
Specific Gravity 1·661
H/U^{235} Atomic Ratio 44·3

Cylinders : 1/16 in. thick Type 3S aluminium

These experiments were performed inside a 9½ ft dia. x 10 ft steel tank filled with water to the level of the fissile solution at critical, (i.e., the array was without top reflection). No corrections were made to the results for end effects due to the structure of the cylinders or the feed line

DELAYED CRITICAL PARAMETERS		
Spacing Between Exterior Surfaces of Cylinders (See Figure 9·6)	Vertex Angle (See Figure 9·6)	Solution Height Above Common Base (in.)
6 in. dia. Cylinders (ID)		
0·15 in.	60°	7·0
	90°	7·7
	120°	8·0
3·0 in.	39°	9·2
	60°	12·3
	90°	14·1
	120°	14·2
8 in. dia. Cylinders (ID)		
0·15 in.	60°	5·7
	90°	6·1
	120°	6·2
3·0 in.	45°	6·6
	60°	7·8
	90°	8·0
	120°	8·0

EXPERIMENTAL RESULTS FOR ARRAYS OF HYDROGEN MODERATED UNITS – HIGHLY ENRICHED

Table 9.22

Three Dimensional Rectilinear Lattices of Cylindrical Units – Air Spaced

Fissile Material : $UO_2(NO_3)_2$ at 92·6 wt.% enrichment. (Total nitrate ion in the solution corresponded to an N/U^{235} atomic ratio of 2·006)
Cylinders : 20·32 cm O.D. x 19·05 cm external height of 0·635 cm thick Plexiglas and containing 5·020 ± 0·003 litres of fissile solution
Array Reflector : Located at the outer boundary of the peripheral lattice cells

In these experiments the cylinders were held in position on an aluminium Unistrut frame by bolted lugs. In the larger arrays as many as five cylinders located near the centre of the lattice, were used as control units and were filled by a remotely operated system through polyethylene tubing. A few measurements were made with a light wooden frame as the spacer. The effect of the additional hydrogeneous material increased the critical spacing by up to 6% over the range examined. Had the support been wooden shelving it is said that the increase in spacing may have been as much as 20%

FISSILE SOLUTION			ARRAY REFLECTOR		DELAYED CRITICAL SPACING BETWEEN EXTERIOR SURFACES OF CYLINDERS (cm)	REFERENCES
Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	Material	Thickness (cm)		
8, (2 x 2 x 2) Unit Arrays[a]						
1·55	-	59	← Unreflected →		1·43	25,26,27
			Paraffin[b]	1·27	3·28	25,27
				(1·27 (top and sides)) (15·24 (base))	3·46	25
				3·81	6·91	25,27
				(3·81 (top and sides)) (15·24 (base))	7·26	25
				7·62	8·48	25
				(7·62 (top and sides)) (15·24 (base))	8·71	25
			Plexiglas	15·24 1·27	8·99 3·00	25,26,27 25
			(Plexiglas (top and sides) (Paraffin (base)[b]	1·27) 15·24)	3·61	25,26
			(Plexiglas (top and sides) (Paraffin (base)[b]	2·54) 15·24)	5·41	25
			(Plexiglas (top and sides) (Paraffin (base)[b]	4·45) 15·24)	7·39	25
			(Plexiglas (top and sides) (Paraffin (base)[b]	6·35) 15·24)	8·64	25
			(Plexiglas (top and sides) (Paraffin (base)[b]	11·43) 15·24)	9·53	25
			(Plexiglas (top and sides) (Paraffin (base)[b]	15·24) 15·24)	9·60	25

259

Table 9.22 (Cont.)

FISSILE SOLUTION			ARRAY REFLECTOR		DELAYED CRITICAL SPACING BETWEEN EXTERIOR SURFACES OF CYLINDERS	REFERENCES
Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	Material	Thickness		
1·373	-	92	← Unreflected →		1·43	25
			Paraffin[b]	(11·43 (top and sides) (15·24 (base)	8·71	25
1·083	-	440	← Unreflected →		Nil (Subcritical k_{eff} ~ 0·5)	25
27, (3 x 3 x 3) Unit Arrays[a]						
1·55	-	59	← Unreflected →		6·48	25,26,27
			Paraffin[b]	1·27	9·08	25,27
				(1·27 (top and sides) (15·24 (base)	9·68	25
				3·81	13·69	25,27
				(3·81 (top and sides) (15·24 (base)	14·27	25
				(77·62 (top and sides) (15·24 (base)	15·85	25
				15·24	16·53	25,26,27
			Plexiglas	1·27	8·76	25
			(Plexiglas (top and sides) (Paraffin (base)[b]	1·27) 15·24)	9·58	25
			(Plexiglas (top and sides) (Paraffin (base)[b]	2·54) 15·24)	11·94	25

Table 9.22 (Cont.)

FISSILE SOLUTION			ARRAY REFLECTOR		DELAYED CRITICAL SPACING BETWEEN EXTERIOR SURFACES OF CYLINDERS (cm)	REFERENCES
Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	Material	Thickness		
1·373	-	92	← Unreflected →		6·40	25
1·083	-	440	← Unreflected →		2·41	25
64, (4 x 4 x 4) Unit Arrays[a]						
1·55	-	59	← Unreflected →		10·67	25,26,27
125, (5 x 5 x 5) Unit Arrays[a]						
1·55	-	59	← Unreflected →		14·40	25,26,27

a. The numbers in parentheses are the dimensions of the arrays expressed in numbers of cylinders
b Density 0·93 gm/cc

Table 9.23

Linear Arrays of Slab Tanks with Larger Surfaces Facing - Air Spaced

(See also Table 9.25)

Fissile Material : UO_2F_2

Slab Tanks : $47\frac{1}{2}$ in. wide, Fabricated in $\frac{1}{4}$ in. thick Type 2S aluminium with $\frac{1}{2}$ in. dia. tie rods at 12 in. centres to minimise wall distortion. The volume average internal thicknesses of the three nominal 3 inch tanks were 3·023 in., 2·997 in., 2·997 in. respectively and that of the nominal 6 in. tank 5·84 in.

FISSILE SOLUTION				ARRAY REFLECTOR	DELAYED CRITICAL PARAMETERS		REFERENCES
Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio		Spacing Between Exterior Surfaces of Tanks (in.)	Solution Height Above Common Base	
Two ~ 3 in. thick Slabs							
93·2	-	480	50·1	Unreflected	0·05 0·95 2·95	12·54 in.[a] 16·8 in.[a] - a,b	22 22 22
93·2	-	481	50·4	Unreflected	0·05 0·95 1·95 2·45	13·13 in. 17·53 in. 23·4 in. 26–27 in. (extrapolated from 24·7 in.)	22 22 22 22
One ~ 3 in. Thick Slab and One ~ 6 in. Thick Slab							
-	-	76·28	337	Unreflected	2·0 15·0 30·0 48·0	32·39 cm 65·81 cm 92·48 cm 113·84 cm	28 28 28 28
Three ~ 3 in. Thick Slabs - Equally Spaced							
-	-	76·28	337	Unreflected	0·0 1·0 3·0 4·5 5·5 6·0	25·50 cm[a] 34·44 cm[a] 58·78 cm[a] 85·52 cm[a] 107·37 cm[a] 120·40 cm[a]	28 28 28 28 28 28
Three ~ 3 in. Thick Slabs - Two Slabs Adjacent							
-	-	76·28	337	Unreflected	0·0 6·0 12·0 18·0	24·87 (Slabs 1, 3 adjacent) 45·03 cm[a] 58·55 cm (Slabs 1, 3 adjacent) 99·74 cm (Slabs 2, 3 adjacent	28 28 28 28

Table 9.23 (Cont.)

FISSILE SOLUTION				ARRAY REFLECTOR	DELAYED CRITICAL PARAMETERS		REFERENCES
Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio		Spacing Between Exterior Surfaces of Tanks	Solution Height Above Common Base	
-	-	76·28	337	Unreflected	12·0	58·19 cm[a]	28
					18	68·30 cm[a]	28
					30·0	86·69 cm (Slabs 1, 3 adjacent)	28
					30·0	93·52 cm (Slabs 2, 3 adjacent)	28
					30·0	83·11 cm	28
One ~ 6 in. thick Slab with Two ~ 3 in. thick Slabs Equally Spaced either side							
-	-	76·28	337	Unreflected	0·0	19·63 cm	28
					10·0	44·25 cm	28
					20·0	62·56 cm	28
					32·0	81·56 cm	28
One ~ 6 in. thick Slab and Two Adjacent ~ 3 in. thick slabs							
93·2	-	-	254	Larger Surface of each slab reflected by 6 in. water (See Figure 9·7)	1·94	8·00 in.	22
					6·0	9·19 in.	22
					11·94	10·13 in.	22
					23·80	10·88 in.	22
					39·75	11·25 in.	22
93·2	-	-	325	Larger Surface of each slab reflected by 6 in. water (See Fig. 9·7)	1·94	8·59 in.	22
					5·84	10·06 in.	22
					11·94	11·13 in.	22
					23·80	12·19 in.	22
-	-	76·28	337	Unreflected	2·0	25·43 cm	28
					6·0	32·79 cm	28
					15·0	44·88 cm	28
					20·0	50·27 cm	28
					30·0	59·72 cm	28
					48·0	73·23 cm	28
					66·0	82·12 cm	28

a. These experiments were performed inside a $9\frac{1}{2}$ ft dia. x 10 ft steel tank

b. Subcritical : is said to be probably subcritical at any height

Table 9.24

Linear Arrays of Slab Tanks with Larger Surfaces Facing, in Water
(Includes additional experiments with water partially replaced by other materials)

Fissile Material : UO_2F_2

Slab Tanks : $47\frac{1}{2}$ in. wide, Fabricated in $\frac{1}{8}$ in. thick Type 2S aluminium with $\frac{1}{4}$ in. dia. tie rods at 12 in. centres to minimise wall distortion
The volume averaged internal thicknesses of the three nominal 3 in. tanks were 3·023 in., 2·977 in., 2·997 in. respectively, and that of the nominal 6 in. tank 5·84 in.

These experiments were performed inside a $9\frac{1}{2}$ ft dia. x 10 ft steel tank filled with water to the level of the fissile solution at critical (i.e., the array was without top reflector)

FISSILE SOLUTION				DELAYED CRITICAL PARAMETERS		REFERENCES
Uranium Enrichment (wt.%)	Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio	Spacing Between Exterior Surfaces of Tanks (in.)	Solution Height Above Common Base	
Two ~ 3 in. thick Tanks						
93·2	-	-	50·1	Nil	-	22
				3		22
				6		22
				10		22
				12		22
				15		22
-	-	76·28	337	0·0	22·99 cm	22,28
				1·0	24·56 cm	22,28
				2·0	32·08 cm	22,28
				3·0	42·11 cm	22,28
				4·0	65·10 cm	22,28
				2·0	30·33 cm (a)	22,28
				4·0	57·07 cm (b)	22,28
				4·0	56·06 cm (c)	22,28
Three ~ 3 in. thick Tanks - Equally Spaced						
-	-	76·28	337	0·0	17·32 cm	22,28
				1·0	19·13 cm	22,28
				3·0	32·92 cm	22,28
				4·5	61·06 cm	22,28
				5·5	111·68 cm	22,28
				6·8	Not critical at 119 cm	22,28
One ~ 6 in. thick Tank and Two Adjacent ~ 3 in. thick Tanks						
93·18	1·108	0·0878	293	6	7·90 in.	29,30
				6	7·93 in. (d)	29,30
				12·1/6	8·74 in. (d)	29,30

Table 9.24 (Cont.)

a. Water between slab tanks partly displaced by a 1 in. thick x 48 in. wide x 12 in. high Plexiglas plate against each tank (see Figure 9.8(a))

b. Water between slab tanks partly displaced by a 1 in. thick x 48 in. wide x 33 in. high Plexiglas plate against each tank (see Figure 9.8(a))

c. Reflector water partly displaced by 1 in. thick x 48 in. wide x 22 in. high Plexiglas plate against the outer surface of each tank (see Figure 9.8(b))

d. Water between slab tanks displaced by Styrofoam, a foam like form of polystyrene, atomic composition CH, density 0·028 gm/cc. The bubbles distributed homogeneously throughout Styrofoam are apparently closed since it is said not to absorb water.

EXPERIMENTAL RESULTS FOR ARRAYS OF HYDROGEN MODERATED UNITS - HIGHLY ENRICHED

Table 9.25

Two Slab Tanks with Larger Surfaces Interacting through Plexiglas or Styrofoam

Reference : 29, 30

Fissile Solution : UO_2F_2 at 87·8 gm U^{235}/litre and 93·18% enrichment
Specific Gravity 1·108
H/U^{235} Atomic Ratio 293

Slab Tanks : 48 in. wide, Fabricated in $\frac{1}{8}$ in. thick aluminium

Array Reflector : All arrays unreflected.

These experiments were performed with one 6 in. wide tank interacting with two 3 in. wide tanks placed in contact to simulate a second 6 in. tank

MATERIALS SEPARATING THE TANKS	SOLUTION HEIGHT ABOVE COMMON BASE (in.)
Tanks Spaced 6 in. Apart	
Air Spaced	11·72
Styrofoam[a]	12·14
Tanks Spaced 12 in. Apart	
Air Spaced	14·01
0·5 in. of Plexiglas centered between tanks (see Figure 9.9(a))	14·26
1·0 in. of Plexiglas centered between tanks (see Figure 9.9(a))	13·74
1·5 in. of Plexiglas centered between slabs (see Figure 9.9(a))	13·77
2·0 in. of Plexiglas centered between tanks (see Figure 9.9(a))	14·36
0·5 in. of Plexiglas against inner surface of each tank (see Figure 9.9 (b))	12·28
1·0 in. of Plexiglas against inner surface of each tank (see Figure 9.9 (b))	11·75
Tanks Spaced 12·1/6 in. Apart	
Air Spaced	14·58
Styrofoam[a]	14·21

a. Atomic composition CH, density 0·028 gm/cc

Table 9.26

Two Slab Tanks in T or L Arrangement - Air Spaced

Reference : 22

Fissile Solution : UO_2F_2 at - gm U^{235}/litre and 93·2 wt.% enrichment
Specific Gravity
H/U^{235} Atomic Ratio 325

Slab Tanks : $47\frac{1}{2}$ in. wide, Fabricated in $\frac{1}{8}$ in. thick Type 2S aluminium with $\frac{1}{2}$ in. dia. tie rods at 12 in. centres to minimise wall distortion. The volume averaged internal thicknesses of the three nominal 3 in. thick tanks were 3·023 in., 2·997 in., 2·997 in. respectively and that of the nominal 6 in. tank 5·84 in.

Array Reflector :

All arrays unreflected

DELAYED CRITICAL PARAMETERS	
Spacing Between the Two arms of Each Assembly (in.)	Solution Height Above Common Base (in.)
One 3 in. thick and One 6 in. thick Tank in T shape (See Figure 9.10 (a))	
3·0	31·5
9·0	37·5
14·0	42·0
One 3 in. thick and One 6 in. thick Tank in L Shape (See Figure 9.10 (b))	
0·5	39·0
6·0	40·5
Two 6 in. thick Tanks in T Shape (a) (See Figure 9.10 (c))	
2·0	18·0
9·0	26·8
19·0	33·0
21·0	33·3
24·5	34·5
Two 6 in. thick Tanks in L Shape (a) (See Figure 9.10 (d))	
1·0	22·5
6·5	23·2
12·0	30·5
14·5	31·5
30·5	36·2 ± 1

a. One 6 in. thick tank mocked up with two adjacent 3 in. thick tanks

Table 9.27

10 in. dia. (ID) Cylindrical Unit Interacting with ~ 6 in. thick Slab Tank - Air Spaced

Reference : 22

Fissile Material : UO_2F_2 at 93·2 wt.% enrichment

Cylinder : 1/16 in. thick Type 2S aluminium

Slab Tank : $47\frac{1}{2}$ in. wide, Fabricated in $\frac{1}{8}$ in. thick Type 2S aluminium with $\frac{1}{2}$ in. thick dia. tie rods at 12 in. centres to minimise wall distortion. Volume averaged internal thickness 5·84 in.

FISSILE SOLUTION			ARRAY REFLECTOR	DELAYED CRITICAL PARAMETERS	
Specific Gravity of Solution	Solution Concentration (gm U^{235}/litre)	H/U^{235} Atomic Ratio		Spacing Between Cylinder and Slab Tank (in.)	Solution Height Above Common Base (in.)
-	-	331	Unreflected (see Figure 9.11 (a))	0·5 6·5 12·0 18·0 30 42	12·0 18·5 22·5 26·5 31·0 35·0
-	-	331	Cylinder wall reflected by a half shell of water $3\frac{1}{2}$ in. thick and large surface of slab by 6 in. water (see Figure 9.11 (b)). Base of both units reflected by $3\frac{1}{2}$ in. water.	6·25 12·19 18·13 30·00	10·56 11·25 11·56 11·81

Table 9.28

30·14 wt.% Enriched UO_2/Paraffin Wax Mixture in Two Rectilinear Parallelepipeds

References 33, 34

These experiments were performed with two identical parallelepipeds of constant, 8 in. x 8 in, facing area and variable height. All except the facing area of both parallelepipeds were reflected by 8 in. thick polyethylene (density 0·919 gm/cc).

FISSILE MIXTURE							MATERIALS SEPARATING THE PARALLELEPIPEDS			DELAYED CRITICAL HEIGHT OF PARALLELEPIPEDS (in.)
Density	U^{235} Density (gm/cc)	Composition (10^{22} nuclei/cc) U^{235}	Hydrogen	Carbon	Oxygen	H/U^{235} Atomic Ratio	Material	Thickness (in.)	Density (gm/cc)	
-	0·608	0·155	6·14	3·05	1·05	35·9	Air (see Figure 9.12(a))	NIL	-	3·46
								0·38		4·00
								1·78		5·50
								3·83		6·75
								Infinite		8·41
-	0·331	0·0848	6·92	3·43	0·574	81·6		NIL		3·05
								0·91		4·00
								1·48		4·50
								2·17		5·00
								3·95		6·00
								Infinite		7·50
-	0·608	0·155	6·14	3·05	1·05	35·9	Polyethylene (see Figure 9.12(b))	1·46	0·919	4·00
								1·80		4·50
								2·76		5·50
								Infinite		6·92
-	0·331	0·0848	6·92	3·43	0·574	81·6		0·15		3·00
								1·06		3·00
								1·32		3·25
								1·53		3·50
								1·94		4·00
								2·34		4·50
								2·84		5·00
								Infinite		6·11
-	0·608	0·155	6·14	3·05	1·05	35·9	Polyethylene/Cadmium (see Figure 9.12(c))	0·23 [a]	0·919 [a]	5·00
								0·51 [a]	[a]	5·50
								Infinite [a]	[a]	7·96
-	0·331	0·0848	6·92	3·43	0·574	81·6		0·07 [a]	[a]	4·25
								0·23 [a]	[a]	4·50
								0·52 [a]	[a]	5·00
-	0·608	0·155	6·14	3·05	1·05	35·9	Polyethylene/Air (see Figure 9.12(d))	2·03	0·919 [a]	5·00
								3·12	[a]	5·50
-	0·331	0·0848	6·92	3·43	0·574	81·6		1·34	[a]	4·00
								2·34	[a]	4·50
								3·62	[a]	5·00

a. Refers to polyethylene only.

Table 9.29

1·42 atomic % Enriched UF_4/Paraffin Wax Mixture in Two Rectilinear Parallelepipeds - H/U^{235} Atomic Ratio 420, Polyethylene Reflector

(see also Table 9.30)

Reference : 35

Fissile Mixture : Density
Uranium density 2·5 gm/cc

These experiments were performed with two identical parallelepipeds with facing areas defined by the width and height measurements given in the Table. All except the facing sides of both parallelepipeds were reflected by 8 in. thick polyethylene (density 0·92 gm/cc).

In one set of experiments the dimensions of the facing areas remained constant and the thickness of the parallelepipeds was increased with increasing separation; in a second set of experiments the base areas remained constant and the height was varied.

DIMENSIONS OF PARALLELEPIPEDS			DELAYED CRITICAL SPACING BETWEEN PARALLELEPIPEDS
Width (cm)	Height (cm)	Thickness (cm)	(cm)
Constant Facing Areas			
92·1	92·3	45·3	0·000
		46·2 *	0·533
		46·2 * 48·7	0·998
		48·7	1·443
		51·3	2·121
		53·9 *	2·771
		53·9 *	3·899
		61·5 61·5	4·943
		66·7	6·541
		71·8	8·436
		75·7	10·363
Constant Base Areas			
46·1	90·6	92·3	0·000
	91·3		0·254
	92·5		0·508
	93·8		0·762
	95·1		0·935
	98·9		1·511
	109·2		2·731
	116·9		3·576

* One parallelepiped of either thickness

Table 9.30

1·42 atomic % Enriched UF_4/Paraffin Wax Mixture in Two Rectilinear Parallelepipeds - H/U^{235} Atomic Ratio 420, Various Reflectors

(see also Table 9.29)

Reference : 36

Fissile Mixture : Density
Uranium density, 2·5 gm/cc

These experiments were performed with two identical parallelepipeds measuring 92·5 cm x 95·1 cm x 46·25 cm with 92·5 cm x 95·1 cm sides facing. Both parallelepipeds were reflected on all sides by 8 in. thick polyethylene (density 0·92 gm/cc) except for the facing sides and one 92·5 x 46·25 cm side of one parallelepiped, which was reflected as indicated in the Table

REFLECTOR (SEE NOTES PREFACING TABLE ALSO FIGURE 9.13)			DELAYED CRITICAL SPACING BETWEEN PARALLELEPIPEDS (cm)
Material	Thickness (cm)	Density (gm/cc)	
Mild Steel	1·27	97·83	0·389
	2·54		0·483
	3·81		0·582
	5·08		0·643
	7·62		0·681
Polyethylene	1·27	0·92	0·478
	2·54		0·594
	5·08		0·732
	10·16		0·757
	15·24		0·775
	20·32		0·775
Water	2·54	1·00	0·541
	5·08		0·617
	7·62		0·660
	10·16		0·668
	15·24		0·673
Concrete	21·6	2·3	0·815
Jabroc (a wood product)	3·8	1·3	0·663
	5·40		0·780
	9·84		0·848
	18·4		0·866

Table 9.30 (Cont.)

REFLECTOR (SEE NOTES PREFACING TABLE, ALSO FIGURE 9.13)			DELAYED CRITICAL SPACING BETWEEN PARALLELEPIPEDS (cm)
Material	Thickness (cm)	Density (gm/cc)	
Plimberboard (a wood product)	1·91 3·81 5·72 7·62 11·43 19·05	0·76	0·417 0·554 0·638 0·711 0·777 0·800

Table 9.31

1·42 atomic % Enriched UF_4/Paraffin Wax Mixture in Two Parallelepipeds - H/U^{235} Atomic Ratio 570

Reference : 37

Fissile Mixture : Density 3·25 gm/cc
Uranium density, 2·15 gm/cc

These experiments were performed with two identical parallelepipeds of constant 92·2 cm x 92·7 cm facing area and variable thickness. All except the facing sides of both parallelepipeds were reflected by 8 in. thick polyethylene (density 0·92 gm cc)

DELAYED CRITICAL PARAMETERS	
Thickness of Parallelepipeds (cm)	Spacing Between Parallelepipeds (cm)
48·5	0·000
48·9	0·257
51·4	1·199
53·9	1·814
61·6	3·622
69·3	5·497
77·1	7·976

EXPERIMENTAL RESULTS FOR ARRAYS OF HYDROGEN MODERATED U^{235} UNITS - INTERMEDIATE AND LOW ENRICHMENTS

Table 9.32

30·45 wt.% Enriched UO_2F_2 Solution in Two Identical 6·09 cm Thick Slab Tanks with Largest Surfaces Facing

Reference : 32

Slab Tanks : 120 cm wide

Array Reflector : The outer large surfaces of the slab tanks were in all cases reflected by thick polyethylene

FISSILE SOLUTION			DELAYED CRITICAL PARAMETERS	
Specific Gravity of Solution	Solution Concentration (gm U/litre)	H/U^{235} Atomic Ratio	Thickness of Material Separating Tanks (cm)	Solution Height Above Common Base (cm)
Air Spaced Systems				
-	-	130	0·27 0·61 1·05 1·41 2·00 2·18	44·9 46·7 48·9 51·1 54·7 55·9
-	-	214	0·14 0·38 0·65 1·03 1·30 1·47	76·2 77·7 82·75 88·75 93·4 96·6
Mild-Steel Spaced Systems				
-	-	130	0·73 0·77	50·95 52·85
Stainless Steel Spaced Systems				
-	-	130	0·13 0·33 0·50 0·73	44·8 46·3 48·75 50·8
Aluminium Spaced Systems				
-	-	130	0·33 0·63 0·97 1·27 1·60 1·93 2·17 3·47	44·5 45·6 46·9 47·7 49·0 50·1 54·5 56·8

Table 9.32 (Cont.)

FISSILE SOLUTION			DELAYED CRITICAL PARAMETERS	
Specific Gravity of Solution	Solution Concentration (gm U/litre)	H/U^{235} Atomic Ratio	Thickness of Material Separating Tanks (cm)	Solution Height Above Common Base (cm)
Polyethylene Spaced Systems				
-	-	130	·27	42·6
			·91	42·2
			1·30	43·3
			1·87	45·9
			2·52	52·2
			2·78	56·6
-	-	214	0·16	7[illegible]·45
			0·30	74·25
			0·49	75·20
			0·97	80·25
			1·30	8[illegible]·55
			1·63	96·45
Perspex Spaced Systems				
-	-	130	0·68	42·9
			1·91	44·1
			2·3[illegible]	46·75
			3·18	50·6
			3·82	56·15
Concrete Spaced Systems				
-	-	130	2·40	49·15
			5·07	58·25
Jabroc [a] Spaced Systems				
-	-	130	0·80	42·9
			1·60	4[illegible]·[illegible]5
			2·27	[illegible]·9
			3·13	53·[illegible]5
Weyroc [b] Spaced Systems				
-	-	130	2·03	49·75
Beechwood Spaced Systems				
-	-	130	1·17	45·25
			2·27	47·1
			3·43	49·9
			4·53	54·3
-	-	214	1·17	80·85
			2·33	91·30

a. Jabroc is a wood product b. Weyroc is a wood product

EXPERIMENTAL RESULTS FOR ARRAYS OF HYDROGEN MODERATED U^{235} UNITS - INTERMEDIATE AND LOW ENRICHMENTS

Table 9.33

30·37 wt.% Enriched UO_2F_2 Solution in Two Identical ~ 3·4 in. Thick Slab Tanks With Larger Surfaces Facing

Reference : 31
Fissile Solution: Concentration
Density 1·4355 gm/cc
H/U^{235} Atomic Ratio = 212·4

Slab Tanks: Material, Stainless Steel
Wall thickness, 0·19 in. (larger surfaces), $\frac{3}{8}$ in. (sides and base)
Dimensions, Height 6 ft (external)
Width 4 ft (external)
Thickness 3·35 ± 0·02 ins and 3·4 ± 0·02 ins (internal) for the two tanks respectively by both direct measurement and volume calibration. The front faces of the tanks bulged slightly at the centre: when the centres were in contact there was a gap of 0·5–0·7 cm between the edges of the tanks

All the corners of the tanks were rounded on a radius of 2 in. and the base of each tank sloped downwards at an angle of about 1° to the horizontal to one corner at which fissile solution entered by a $1\frac{1}{2}$ in. dia. stub pipe

Each tank was equipped with a $\frac{1}{2}$ in. o.d., $\frac{3}{8}$ in. i.d. sparge pipe dipping down to the base of the tank, 8 in. off centre, and with a sight glass and scale

These experiments were performed with the slab tanks bolted to supporting frameworks above a horizontal steel table The distance between the centre of the external base of each tank and the table top was 11·7 in.

Results were obtained with three different reflectors against the outer large surface of each tank, (a) 8 in. graphite (density 1·65 gm/cc), (b) 8 in. polyethylene (c) 9 in. concrete (A.E.R.E., U.K.A.E.A. Specification No. 338, Issue 4, made from clean graphite aggregate density 2·3 grms per cc). Two 8 in. square x 30 in. square x 30 in. blocks of graphite lying lengthwise away from the tanks had to be used at one corner of each tank to complete the graphite reflector (see Figure 9.14)

The Reflector behind the 3·4 in. tank rested on a framework with the lower edge level with the base of the tank. The reflector behind the 3·35 in. tank extended 9·4 cm below the exterior base of the tank and rested on an 8 in. square x 48 in. block of polyethylene placed on the table top. The graphite and polyethylene reflectors covered the width of the tank with no overlap at the side edges but the concrete reflector projected 3 in. at either side. The heights of the various reflectors above the internal base of either tank were:

	3·4 in. Tank	3·35 in. Tank
Graphite	140·7 cm	96·4 cm
Polyethylene	6 ft	6 ft
Concrete	150·7 cm	150·7 cm

Where the tanks were separated by a material medium this extended 9·4 cm below the external base of each tank and rested on an 8 in. thickness of polyethylene placed on the table top and extending under the 3·4 in. tank (see Figure 9·14).

The cadmium cladding used in some of the experiments was 0·031 in. thick and covered the inner large surface of both tanks, extending from 9·4 cm below the external base of the tank to 50·7 cm or 112·6 cm above the internal base, whichever was more appropriate

MATERIALS SEPARATING THE TANKS (SEE ALSO NOTES PREFACING THE TABLE)					DELAYED CRITICAL SOLUTION HEIGHT ABOVE COMMON BASE (in.)
Material	Height Above Internal Base of Either Tank	Overlap Either Side of Tanks	Thickness (in.)	Density (gm/cc)	
8 in. Graphite Reflected Systems					
Air	-	-	Nil	-	9·06
			1		10·4
			2		11·7

Table 9.33 (Cont.)

MATERIALS SEPARATING THE TANKS (SEE ALSO NOTES PREFACING THE TABLE)					DELAYED CRITICAL SOLUTION HEIGHT ABOVE COMMON BASE
Material	Height Above Internal Base of Either Tank (cm)	Overlap Either Side of Tanks (in.)	Thickness (in.)	Density (gm/cc)	(in.)
			4 6 8 10·63 12·55 13·21 15·63 17·33 20·68		14·1 16·5 19·1 22·5 25·1 26·0 29·49 33·0 38·0
Mild Steel [a]	50·5	Nil	0·79 1·85 3·89 5·98 10·78	7·79	10·12 11·02 12·40 13·43 14·96
Polyethylene	111·4	5½	0·52 1·04 3·13 5·21 6·25 8·3 10·1	0·93	9·5 10·6 17·9 25·6 27·8 30·0 30·8
Polyethylene/Cadmium [b]	111·4	5½	Nil 1·06 (Excluding Cadmium) 2·17 (Excluding Cadmium)	0·93	10·98 18·98 34·17
Concrete	55·8	8	1·1 2·2 4·3 6·5 8·6 10·8 13·0 16·2	2·3	9·7 [c] 10·5 [c] 12·4 [c] 14·3 [c] 16·3 [c] 17·9 [c] 19·1 [c] 20·4 [c]
Concrete/Cadmium	55·8	8	1·08 (Excluding cadmium) 2·16 (Excluding cadmium) 4·32 (Excluding cadmium) 6·48 (Excluding cadmium) 11·16 (Excluding cadmium) 13·32 (Excluding cadmium)	2·3	12·32 [d] 13·74 [d] 17·01 [d] 21·02 [d] 29·25 [d] 30·55 [d]
High density γ ray shield, Barytes concrete	50·6	8	8·82	3·6	17·05

Table 9.33 (Cont.)

MATERIALS SEPARATING THE TANKS (SEE ALSO NOTES PREFACING THE TABLE)					DELAYED CRITICAL SOLUTION HEIGHT ABOVE COMMON BASE (in.)
Material	Height Above Internal Base of Either Tank (cm)	Overlap Either Side of Tanks (in.)	Thickness (in.)	Density (gm/cc)	
Jabroc *	111·4	8	0·63	1·32	9·37
			1·89		11·02
			4·41		16·26
			6·54		20·43
			8·74		22·87
			10·83		24·06
Jabroc/Cadmium *	111·4	8	0·63 (Excluding cadmium)	1·32	13·19
			1·97 (Excluding cadmium)		20·63
			2·64 (Excluding cadmium)		25·71
			2·91 (Excluding cadmium)		28·35
Beechwood	111·4	8	1·02	0·735	9·69
			2·83		11·54
			4·86		14·37
			6·69		17·4
			8·58		20·2
			10·67		22·7
			13·54		24·76
			16·46		25·94
			19·29		26·65
Beechwood/Cadmium	111·4	8	1·02 (Excluding cadmium)	0·735	13·58
			2·87 (Excluding cadmium)		20·87
			3·86 (Excluding cadmium)		25·98
			4·72 (Excluding cadmium)		31·56
8 in. Polyethylene Reflected Systems					
Air	-	-	Nil	-	11·38
			2·0		16·33
			4·0		21·69
			7·3		33·78
			8·63		40·24
			10·0		48·86
			10·075		49·45
9 in. Concrete Reflected Systems					
Air	-	-	Nil	-	10·4
			2		14·2
			4		18·0
			6·19		22·5
			8·91		28·6
			9·91		31·7

Table 9.33 (Cont.)

MATERIALS SEPARATING THE TANKS (SEE ALSO NOTES PREFACING THE TABLE)					DELAYED CRITICAL SOLUTION HEIGHT ABOVE COMMON BASE (in.)
Material	Height Above Internal Base of Either Tank (cm)	Overlap Either Side of Tanks (in.)	Thickness (in.)	Density (gm/cc)	
9 in concrete	50·7	8	1·08	2·3	11·38
			2·16		12·6
			4·32		15·31
			6·48		19·65
	150·7	Nil - 8 (not uniform)	10·08	2·3	27·64
			12·24		31·10
			14·4		33·43
			16·56		35·31

a. BS 15 No. 1 Quality, density 7·87 gm/cc

b. 0·6 cm thick aluminium plate next to face of 3·35 in. tank

c. Graphite reflector height 93·7 cm above internal base of either tank

d. Graphite reflector height 93·7 cm above internal base of either tank

e. Jabroc is a wood product, the material used in these experiments was the high density Type N

f. Polyethylene reflector height, 60·6 cm above internal base of tank

EXPERIMENTAL RESULTS FOR ARRAYS OF UNITS OF DIFFERING U^{235} MATERIALS

Table 9.34

2x2x2[a] Arrays of Four 93·2 wt.% Enriched Uranium Metal Cylinders Interacting with Four 92·6 wt.% Enriched $UO_2(NO_3)_2$ Solution Cylinders

Array Reflector: All arrays air-spaced and unreflected

These arrays were formed by bringing together one half of each of two different critical lattices of 8(2x2x2)[a] cylinders along a common horizontal centre line until their cell boundaries coincided. (The metal lattices are described in Table 9.2 and the solution lattices in Table 9.22)

METAL LATTICE		SOLUTION LATTICE		REACTIVITY OF COMPOSITE ARRAY
Cylinder Mass (kgm U)	Spacing Between Exterior Surfaces of Cylinders	H/U^{235} Atomic Ratio in Solution	Spacing Between Exterior Surfaces of Cylinders	
20·960	2·248 cm	59	1·43 cm	More than one dollar subcritical, apparent source neutron multiplication ~ 20 Array made critical by reducing the spacing between the metal cylinders to 1·689 cm
21·008	1·466 cm	59	1·43 cm	More than one dollar subcritical, apparent source neutron multiplication ~ 20

a. This denotes the dimensions of the array expressed in numbers of cylinders

Table 9.35

Slab Tank of 30·45 wt.% Enriched UO_2F_2 Solution Interacting with Rectilinear Parallelepiped of 1·42 atomic % Enriched UF_4/Paraffin Wax Mixture

Reference : 38

UO_2F_2 Solution : Specific gravity - Specific gravity

Concentration - UF_4/Wax Mixture : U^{235} density - Density -

H/U^{235} atomic ratio, 112 ; H/U^{235} atomic ratio, 572

Slab Tank : 6·09 cm thick, 120 cm wide ; Parallelepiped : 61·6 cm thick, 123 cm wide

The experimental arrangement is shown in Figure 9.15

DELAYED CRITICAL PARAMETERS	
Thickness of Material Separating Fissile Units (cm)	Height of Fissile Units Above Common Base (cm)
Air Spaced Systems	
0·25	63·7
0·58	64·5
1·12	67·1
2·24	72·2
3·34	77·4
5·55	87·7
7·85	98·0
10·32	108·4
Mild Steel Spaced Systems	
0·69	74·2
1·98	91·0
Stainless Steel Spaced Systems	
0·58	75
Polyethylene Spaced Systems	
0·64	61·6
2·70	76·4
4·44	108·4

Table 9.35 (Cont.)

DELAYED CRITICAL PARAMETERS	
Concrete Spaced Systems	
2·70	70·8
8·56	92·7
11·43	106
Jabroc [a] Spaced Systems	
4·05	74·1
4·92	81·1
6·73	105·8

a. Jabroc is a wood product.

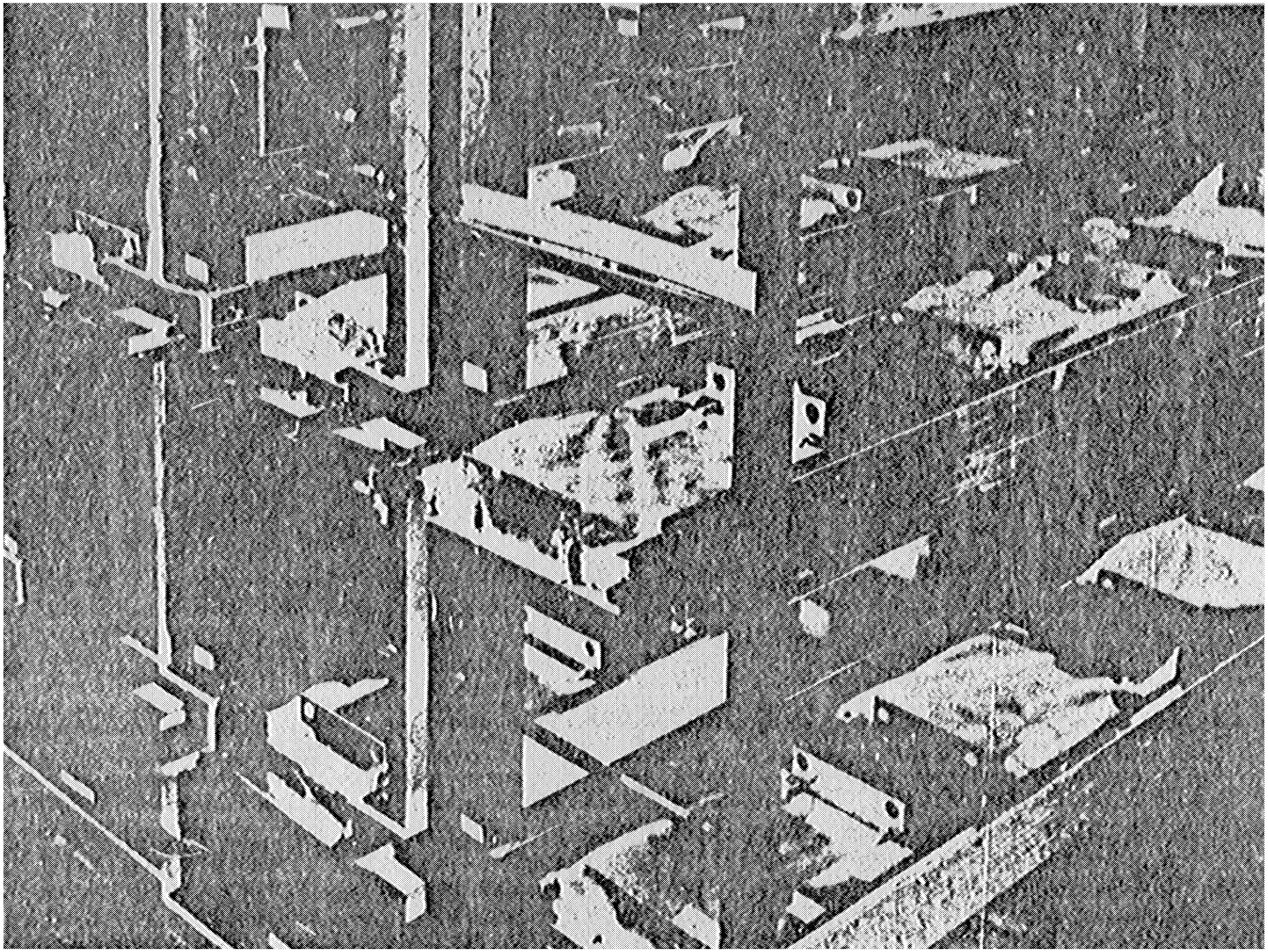


Figure 9.1 (See Table 9.8)

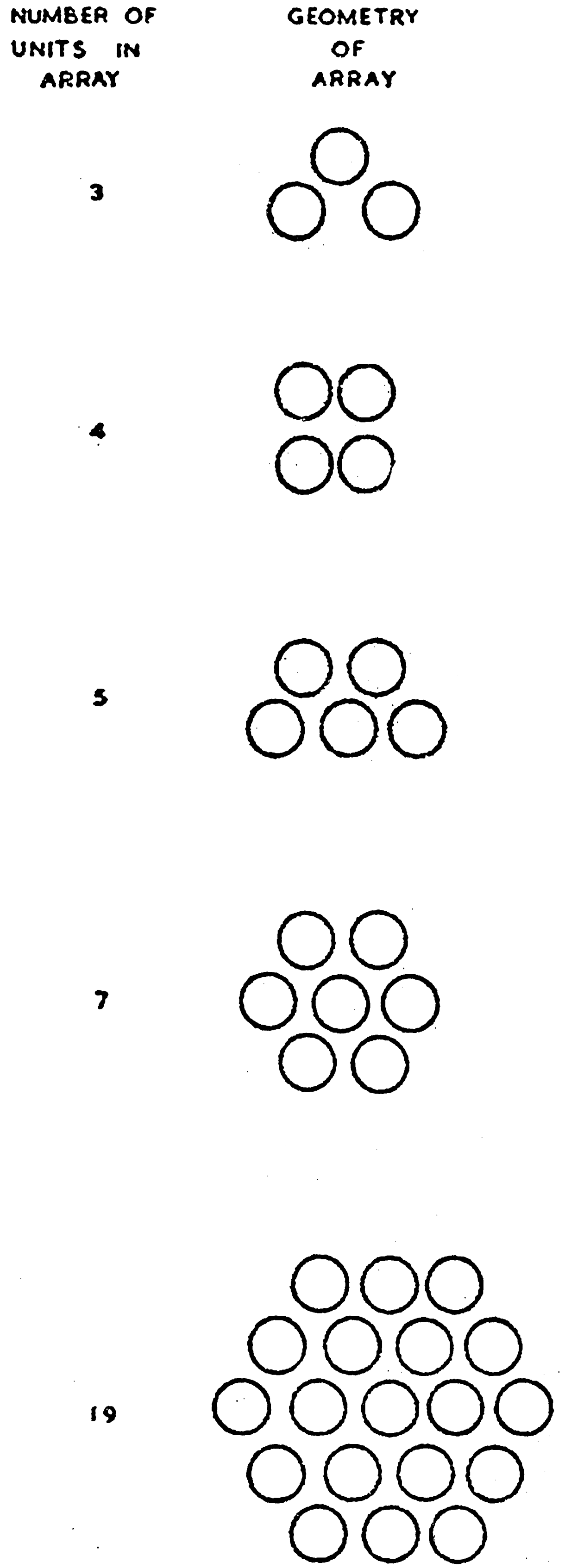
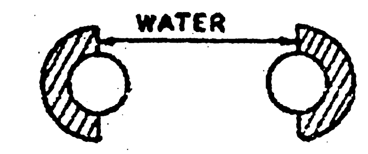


FIG. 9·3 (SEE TABLES 9·12, 9·13, 9·14 AND 9·15)



4" THICK PLEXIGLAS BASE REFLECTORS.

FIG. 9·2 (SEE TABLE 9·10)

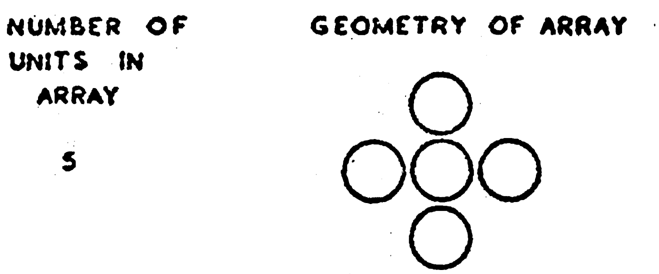


FIG. 9·4 (SEE TABLE 9·12)

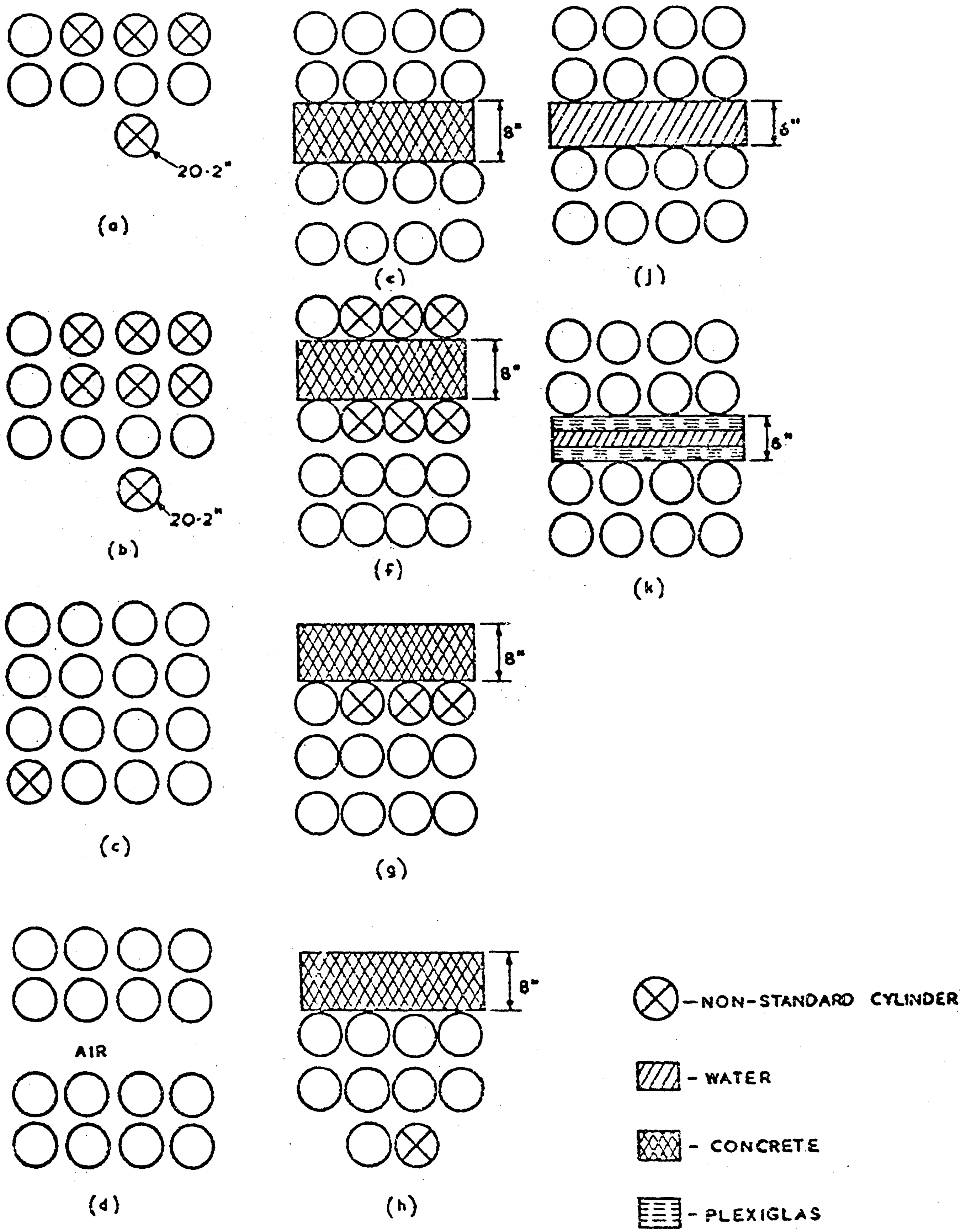


FIG. 9-5 (SEE TABLE 9-19)

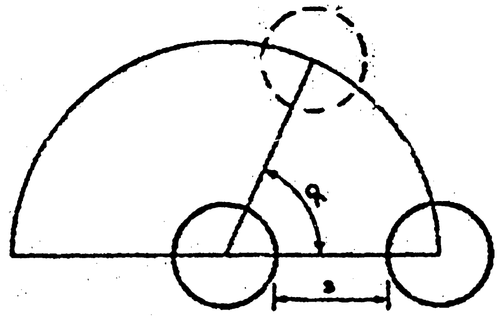


FIG. 9·6. (SEE TABLES 9·20 AND 9·21)

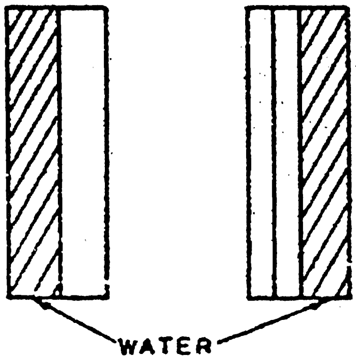


FIG. 9·7. (SEE TABLE 9·23)

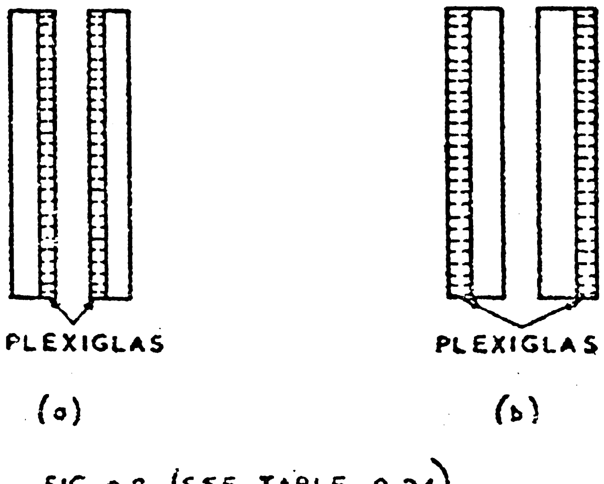


FIG. 9·8. (SEE TABLE 9·24)

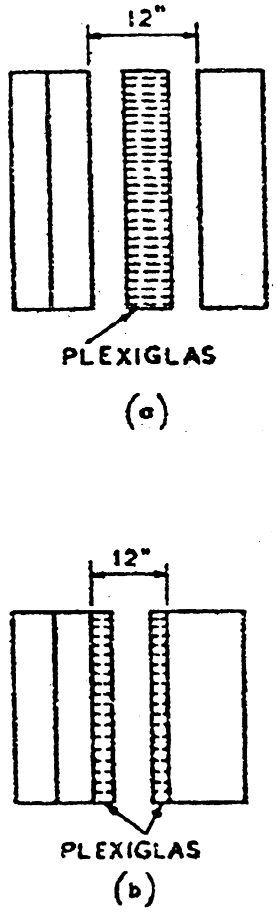


FIG. 9.9 (SEE TABLE 9.25)

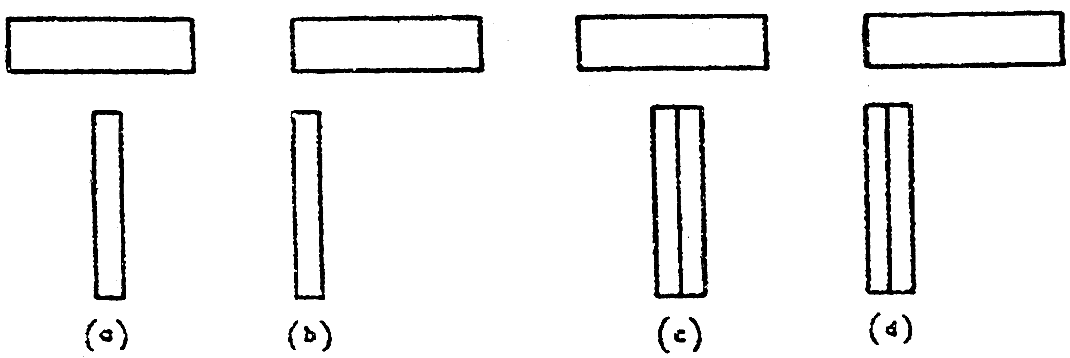


FIG. 9.10 (SEE TABLE 9.26)

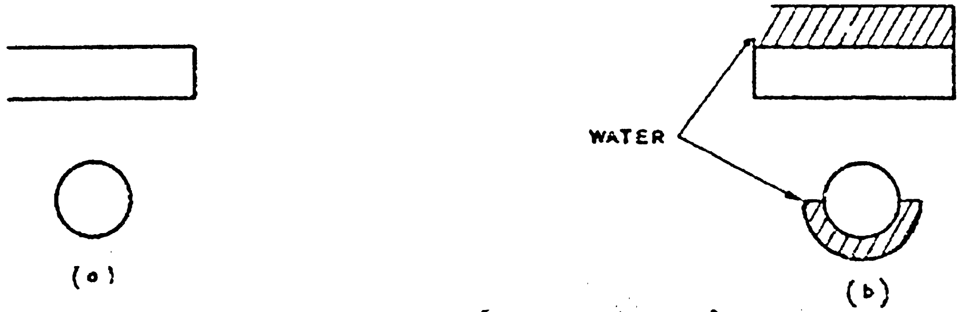


FIG. 9·11 (SEE TABLE 9·27)

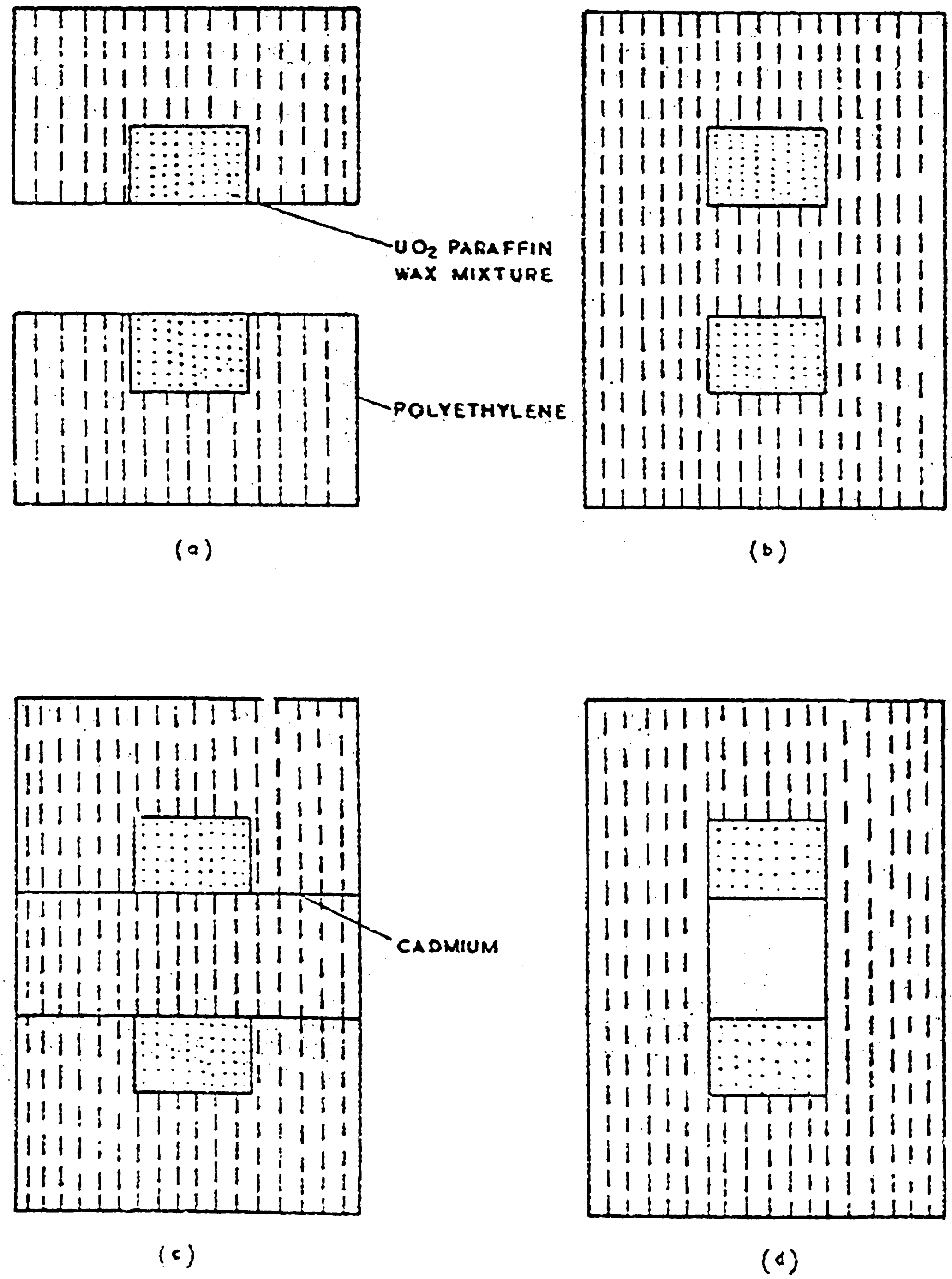


FIG 9·12 (SEE TABLE 9·28)

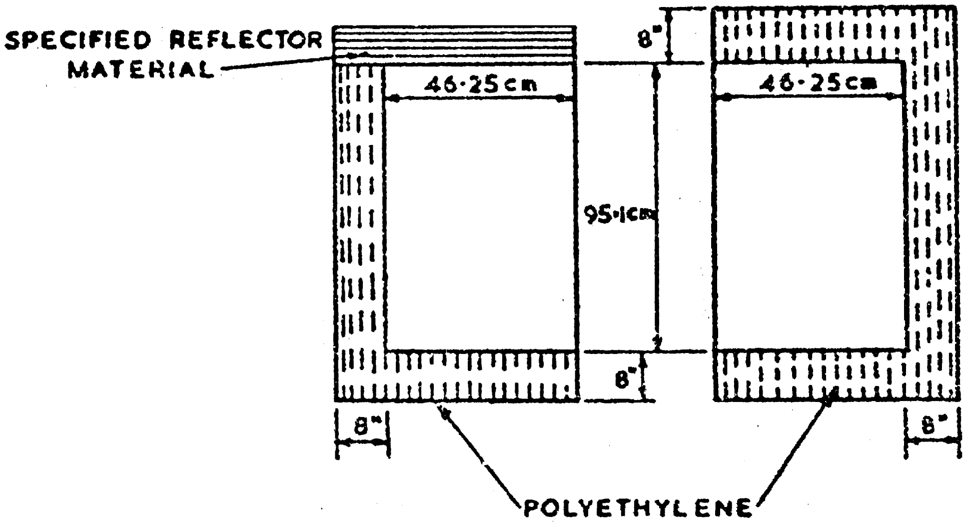


FIG. 9-13 (SEE TABLE 9-30)

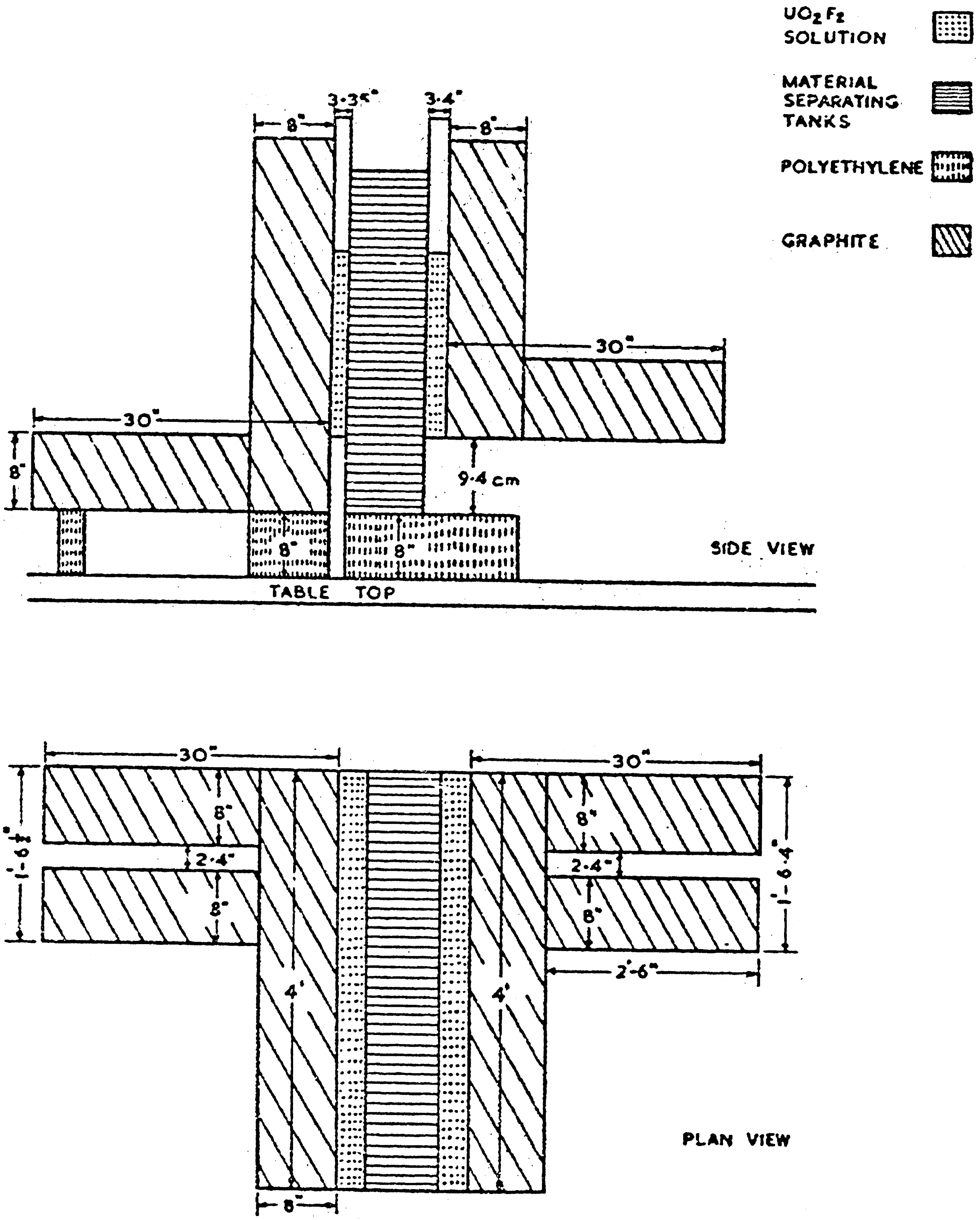


FIG. 9·14 (SEE TABLE 9·35)

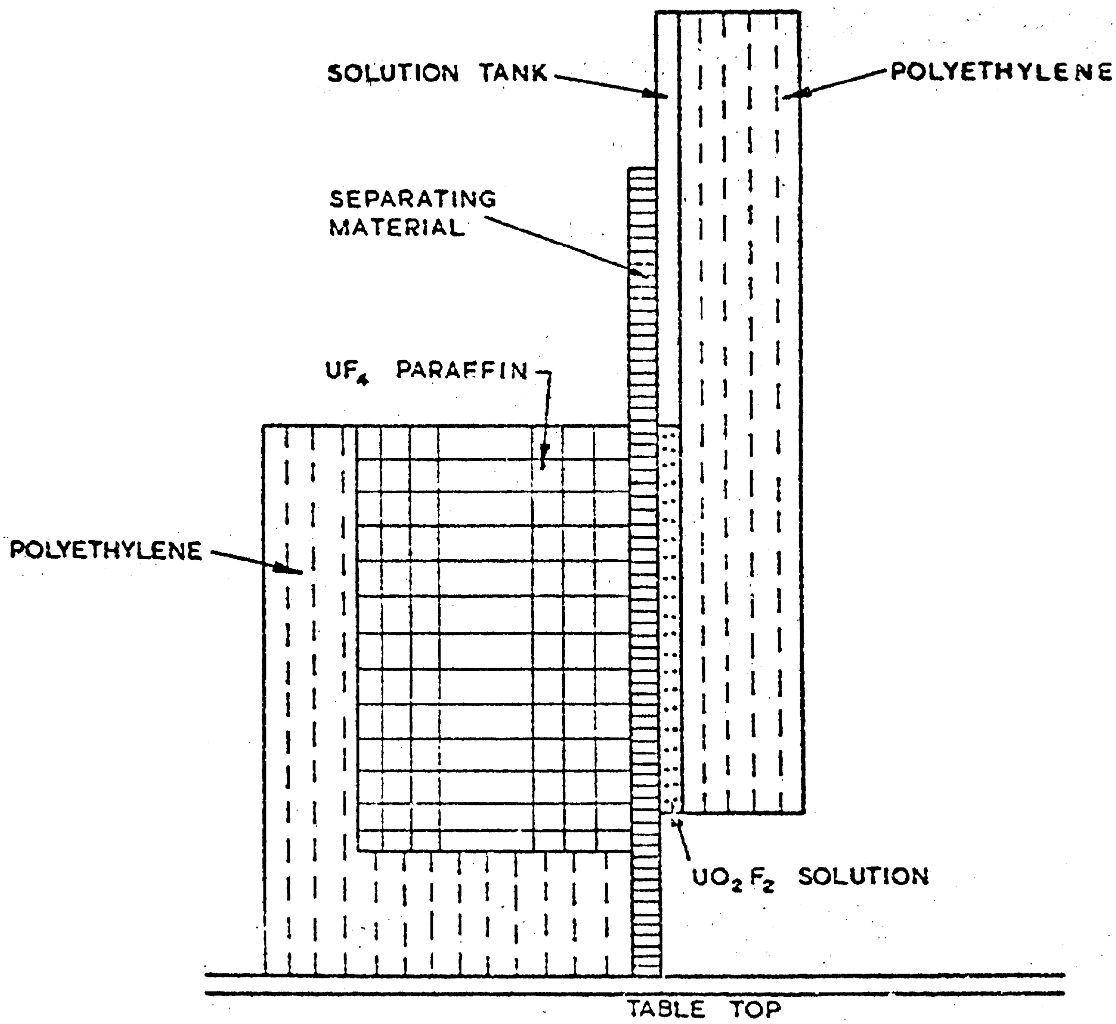


FIG. 9·15 (SEE TABLE 9·33)

CHAPTER 10 - LATTICES

CHAPTER 10 - CONTENTS

CHAPTER 10 - REFERENCES

1. REDMAN, W. C., KAUFMANN, S. G., and ARMSTRONG, J. W. Heterogeneous Critical Experiments with ThO_2, UO_2 and D_2O; 2nd Winter ANS Meeting, N.Y., Oct. 28-31, 1957, Session 2, Paper 8

2. REDMAN, W. C., and THIE, J. A. Properties of Exponential and Critical System of Thoria-Urania and Heavy Water, and Their Application to Reactor Design, in Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958, P/600

3. ARMSTRONG, J. W., BEIDELMANN, J. A., KAUFMANN, S. G., and PLUMLEE, K. E. Experiments with Thoria-Urania D_2O Criticals, Trans. Am. Nucl. Soc. 1(1): 99(1958)

4. REDMAN, W. C., KAUFMANN, S. G., PLUMLEE, K. E., and BAIRD, Q. L. Critical Experiments with Thoria-Urania Fuel in Heavy Water, USAEC Report ANL-6378, Argonne National Laboratory, December, 1961

5. KRASIN, A. K., DUBOUSKY, B. G., LANTROV, M. N., GLAYKOV, Y. Y., GONCHOROV, R. K., KAMAYER, A. V., GERASEVA, L. A., VANILOV, V. V., MYUTIN, E. I., and SENCHENKOV, A. P. Physical Characteristics of Beryllium Moderated Reactor, in Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958, P/2146

6. CAMPBELL, R. W., DOYAS, R. J., FIELD, H. C., GUDERJAHN, C. A., GUENTHER, R. L., HAUSKNECHT, D. F., MAYER, M. S., and MOREWITZ, H. A. Critical Experiments on Slightly Enriched Uranium Metal Fuel Elements in Graphite Lattices, USAEC Report NAA-SR-7541 Atomic International

7. KRASIK, S., and RADKOWSKY, A. Pressurised Water Reactor (P.W.R.) Critical Experiments in Proceedings of the First International Conference on the Peaceful Uses of Atomic Energy, Geneva 1955, P/601

8. KOUTS, H., SHER, R., BROWN, J. R., KLEIN, D., STEIN, S., HELLENS, R. L., and ARNOLD, A. Physics of Slightly Enriched, Normal Water Lattices (Theory and Experiment), Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva 1958, P/1841

9. LLOYD, R. C., CLAYTON, E. D., and HANDLER, H. E. Criticality Parameters for Lattices with 1·6% Enriched Uranium Rods in Light Water, in Nuclear Physics Quarterly Report April, May, June, 1958, USAEC Report HW56919, Hanford Laboratories, July 21, 1958

10. DAVISON, P. W. Measurements on a Lattice of Stainless Steel Clad Slightly Enriched Uranium Dioxide Fuel Rods in Light Water, in Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva 1958, P841/Add.1

11. DAVISON, P. W., BERG, S. S., BERGMANN, W. H., HANLEN, D. F., JENNINGS, B., LEAMER, R. D., and HOWARD, J. E. Yankee Critical Experiments - Measurements on Lattices of Stainless Steel Clad, Slightly Enriched Uranium Dioxide Fuel Rods in Light Water, USAEC Report YAEC 94, Westinghouse Electric Corporation, April 1, 1959

EXPERIMENTAL RESULTS FOR U^{235} FUELLED. DEUTERIUM MODERATED LATTICES

Table 10·1

UO_2/ThO_2 Mixture Fuel (93·2 wt % enriched uranium)

References: 1, 2, 3, 4.

Fuel Rods: Assembled by stacking fuel slugs in a 0·787 cm OD x 157·5 cm Type 2S aluminium tube sealed at either end by a brazed in aluminium plug. Two types of rod were used:

	1	2
Th/U^{235} ATOMIC RATIO	24·65	15·00
CLADDING THICKNESS	0·089 cm	0·034 cm
LENGTH OF FUELLED SECTIONS	152·64 cm	152·40 cm
WEIGHT OF FUEL	357·2 gm	434·6 gm
OXYGEN CONTENT OF FUEL	12·15 wt %	-

Lattice Type: Hexagonal

Moderator/Reflector: 97·0 - 99·4 wt % D_2O

These experiments were performed with the fuel rods orientated vertically in a 205·7 cm dia tank of heavy water, maintaining the cross-section of the core as near circular as possible. The fuel rods were supported in three aluminium matrix plates perforated with 0·794 cm dia holes on a 0·953 cm hexagonal pitch and themselves supported at the edge by rods connected to a 0·953 cm thick aluminium base plate. The base plate rested on an aluminium supporting structure 30 cm above the base of the tank. Four control rod guides situated at the corners of a central 61 cm square section of the lattice each weighed 16·9 kgm and were formed from 0·318 cm thick ASTM Type 6061 aluminium sheet bent to the shape of a 1·27 cm wide cross-shaped channel, span 26·7 cm. The results recorded in the table all refer to systems with the control rods withdrawn and the guides filled with moderator, control being exercised by varying the moderator level.

CORE		DELAYED CRITICAL PARAMETERS			
Lattice Pitch (cm)	D/U^{235} Atomic Ratio	Number of Rods	Core Diameter	Moderator Height (above Lower End of Fuelled Section of Rods) (cm)	Mass
Th/U^{235} = 24·65 FUEL					
1·906	-	665	-	150·88	-
		685	-	145·40	-
		685	-	159·13	-
		745	-	132·84	-
		745	-	135·08	-
		745	-	139·09	-
		805	-	123·53	-
		867	-	115·95	-
		925	-	111·05	-
		926	-	110·03	-
		945	-	109·30	-
		977	-	104·70	-
		1009	-	103·30	-
		1526	-	76·74	-
2·859		325	-	148·22	-
		325	-	> 157	-
		353	-	133·79	-
		375	-	125·20	-
		375	-	132·21	-

Table 10.1 (Cont'd)

CORE		DELAYED CRITICAL PARAMETERS			
Lattice Pitch (cm)	D/U^{233} Atomic Ratio	Number of Rods	Core Diameter	Moderator Height (above Lower End of Fuelled Section of Rods) (cm)	Mass
Th/U^{233} = 24·65 FUEL					
		405	-	115·81	-
		421	-	111·85	-
		461	-	103·70	-
3·812	-	257	-	154·97 [a]	-
		266	-	147·61	-
		266	-	> 178	-
		283	-	137·08	-
		299	-	129·35	-
		299	-	> 178	-
		331	-	148·74	-
		339	-	143·66	-
5·718	-	1082	-	104·33	-
Th/U^{233} = 15·00 FUEL					
1·906	-	345	-	132·97	-
		366	-	123·04	-
		421	-	104·58	-
		495	-	90·16	-
		593	-	78·90	-
		687	-	71·78	-
2·859	-	163	-	150·81	-
		190	-	115·47	-
		321	-	72·38	-
		429	-	59·73	-
3·812	-	139	-	127·32	-
		163	-	103·05	-
		247	-	72·79	-
5·718	-	134	-	137·15	-
		147	-	122·10	-
		176	-	103·58	-

EXPERIMENTAL RESULTS FOR U^{235} FUELLED, BERYLLIUM MODERATED LATTICES

Table 10.2

10 wt% Enriched U_3O_8 Fuel

Reference: 5

Fuel Rods: Assembled by packing U_3O_8 powder into the annular space between two concentric stainless-steel tubes 1·34 cm dia x 0·02 cm wall-thickness and 0·9 cm dia x 0·04 cm wall-thickness respectively. Weight of U_3O_8 per 96 cm long rod, 214 gm.

Lattice Type: 10·7 x 6·4 cm rectangular unit cell with a 1·7 cm dia channel at the centre surrounded, at a radius of 2 cm, by six 1·45 cm dia channels. All seven channels were available to fuel rods.

Moderator: Beryllium metal.

These experiments were performed with the fuel rods oriented vertically in a 104 cm dia ventical cylinder of the beryllium (weight 1200 kgm at the maximum height of 96 cm), constituting a total of 128 unit lattice cells. The cylinder was also penetrated by 3·1 cm dia horizontal channels in a rectangular 10·7 x 8·0 cm lattice. When not required for other purposes (see Table) all channels in the beryllium cylinder were filled with graphite slugs. The core was unreflected axially except for a thin steel supporting plate.

NO. OF FUEL RODS PER UNIT CELL	VOLUME RATIOS			ATOMIC RATIOS			DELAYED CRITICAL PARAMETERS		
	Be/U_3O_8	C/U_3O_8	H_2O/U_3O_8	Be/U^{235}	C/U^{235}	H/U^{235}	Core[a] Diameter (cm)	Core Height (cm)	U^{235} Mass (kgm)
'DRY' SYSTEMS									
4				3112	463	NIL	80·8	96	5·46
							104	90	8·78
5				2486	337	NIL	75·0	96	5·86
							104	88	10·70
6				2075	255	NIL	73·0	96	6·66
							104	89	11·70
7				1777	113	NIL	75·0	96	8·26
SYSTEMS WITH CENTRE OF EACH FUEL ELEMENT FILLED WITH WATER									
4				3112	401	72	63·0	96	3·31
							104	74	7·23
5				2486	273	72	56·8	96	3·36
							104	67	8·16
6				2075	190	72	52·4	96	3·42
							104	63	8·30
7				1777	113	72	49·2	96	3·53

Table 10.2 (Cont'd)

NO. OF FUEL RODS PER UNIT CELL	VOLUME RATIOS			ATOMIC RATIOS			DELAYED CRITICAL PARAMETERS		
	Be/U_3O_8	C/U_3O_8	H_2O/U_3O_8	Be/U^{235}	C/U^{235}	H/U^{235}	Core[a] Diameter (cm)	Core Height (cm)	U^{235} Mass (kgm)
SYSTEMS WITH CENTRE OF EACH FUEL ELEMENT AND ALL HORIZONTAL CHANNELS[b] FILLED WITH WATER									
4				3112	202	242	67·4	104	3·78
							90	73·7	7·20
5				2486	115	208	56·4	104	3·62
							104	62	7·55
6				2075	58	186	53·6	96	3·60
							104	57	7·51
7				1777	NIL	170	50·2	96	3·69

a. Calculated on an equal area basis, the cross-sectional area of the core being taken as the product of the unit cell area and the number of unit cells

b. The water in the horizontal channels was contained in 30 cm dia x 0·1 cm wall thickness aluminium tubes

Table 10.3

2·0 wt % Enriched Metal Fuel

Reference: 6.

Fuel Rods: 8 ft in length; assembled by stacking hollow fuel slugs in a 0·04 in. thick walled aluminium tube. The slugs were 1·026 in. OD, 1·730 in. ID x 12 in. and were clad in 0·003 in. thick nickel.

Lattice Type: Hexagonal.

Moderator/Reflector: Union Carbide Co. Ltd. AGOT graphite, (density 1·70 gm/cc, 2200 in./sec. absorption cross-section 4·07 mb).

These experiments were performed using a 12 ft dia (across flats) x 8 ft vertical, dodeconal cylinder of graphite assembled from hexagonal prisms measuring 4 in. across the flats. The fuel rods were inserted into 1·937 in. diameter holes drilled axially through appropriate prisms. For each core the rods were loaded in successive concentric hexagonal rings, thus maintaining the core cross-section as nearly circular as possible. The core was unreflected axially except for a supporting steel grid-plate.

CORE			DELAYED CRITICAL PARAMETERS		
Lattice Pitch (in.)	C/Fuel Volume Ratio	C/U^{235} Atomic Ratio	Number of Rods	Approximate Core Diameter (Maximum) (ft)	Mass
6·93	25·12	-	30·83	-	-
8·00	34·45	-	22·54	-	-
10·58	61·76	-	18·21 - 18·39	-	-
12·00	79·97	-	18·78 - 18·90	4	-
13·86	107·24	-	23·24 - 23·44	6	-
16·00	143·60	-	34·62	8	-

EXPERIMENTAL RESULTS FOR U^{235} FUELLED, HYDROGEN MODERATED LATTICES

Table 10.4

1·145 wt% Enriched Metal Fuel

Reference: 7, 8

Fuel Rods: 0·600 in. dia x 48 in. clad in 0·028 in. thick aluminium and fitted with 3 in. end plugs to which aluminium end-pieces equal in diameter to the rod are attached. The I.D. of the aluminium cladding is 0·010 in. larger than the O.D. of the uranium rod.

Lattice Type: Hexagonal

Moderator/Reflector: Water

These experiments were performed in a water tank with the fuel rods suspended by the top end-piece from holes in a 2 in. thick aluminium support plate, and the lower ends fitted into a thinner aluminium guide plate. Support and guide plates were connected at the edges by aluminium rods, several pairs of plates being available to give different lattice spacings. The core cross-section was maintained as nearly circular as possible and an effectively infinite water reflector is said to have been maintained on all sides of the core.

CORE			DELAYED CRITICAL PARAMETERS		
Lattice Pitch (cm)	Water/U Volume Ratio	H/U^{235} Atomic Ratio	Number of Rods	Core[a] Diameter (cm)	Mass
2·616	2·017	-	463	59·12	-
2·990	3·011	-	380	61·20	-

a. Calculated on an equal area basis, the cross-sectional area of the core being taken as the product of the unit cell area and the number of unit cells

Table 10.5

1·295 wt % Enriched Metal Fuel

References: 7, 8.

Fuel Rods : 48 ins in length; clad in 0·028 ins thick aluminium and fitted with 3 ins end plugs to which aluminium end-pieces equal in diameter to the rod are attached. The I.D. of the aluminium cladding is 0·010 ins larger than the O.D. of the uranium rod.

Lattice Type: Hexagonal.

Moderator/Reflector: Water.

The experiments were performed in a water tank with the fuel rods suspended by the top endpiece from holes in a 2 in. thick aluminium support plate, and the lower ends fitted into a thinner aluminium guide plate. Support and guide plates were connected at the edges by aluminium rods and several pairs of plates were available to give different lattice spacings. The core cross-section was maintained as nearly circular as possible and an effectively infinite water reflector is said to have been maintained on all sides of the core.

CORE			DELAYED CRITICAL PARAMETERS		
Lattice Pitch (cm)	Water/U Volume Ratio	H/U^{235} Atomic Ratio	Number of Rods	Core[a] Diameter (cm)	Mass
0·600 in. dia Fuel Rods					
2·404	1·515	-	478	55·22	-
2·616	2·017	-	335	50·28	-
2·990	3·011	-	266	51·20	-
0·387 in. dia Fuel Rods					
1·725	2·024	-	904	-	-
1·961	3·018	-	631	51·72	-

a. Calculated on an equal-area basis, the cross-sectional area of the core being taken as the product of the unit cell area and the number of unit cells

Table 10.6

1·311 wt % Enriched UO_2 Fuel

Reference: 8

Fuel Rods: 48 ins in length; clad in 0·028 in. thick aluminium and fitted with 3 in. end plugs to which aluminium end-pieces equal in diameter to the rod are attached. The I.D. of the aluminium cladding is 0·010 in. larger than the O.D. of the uranium rod.

Lattice Type: Hexagonal

Moderator/Reflector: Water

These experiments were performed in a water tank with the fuel rods suspended by the top end-piece from holes in a 2 in. thick aluminium support plate, and the lower ends fitted into a thinner aluminium guide plate. Support and guide plates were connected at the edges by aluminium rods and several pairs of plates were available to give different lattice spacings. The core cross-section was maintained as nearly circular as possible and an effectively infinite water reflector is said to have been maintained on all sides of the core.

CORE			DELAYED CRITICAL PARAMETERS		
Lattice Pitch (cm)	Water/U Volume Ratio	H/U^{235} Atomic Ratio	Number of Rods	Core[a] Diameter (cm)	Mass
0·601 in. dia Fuel Rods					
2·205	3·048	-	1269	-	-
2·359	4·000	-	1027	-	-
2·512	5·000	-	987	-	-
0·388 in. dia Fuel Rods					
1·558	3·953	-	3045	-	-
1·652	4·947	-	2704	-	-
0·383 in. dia Fuel Rods					
1·558	2·904	-	2173	-	-
1·652	3·622	-	1755	-	-
1·806	4·878	-	1575	-	-

a. Calculated on an equal-area basis, the cross-sectional area of the core being taken as the product of the unit cell area and the number of unit cells

Table 10.7

1·6 wt. % Enriched Metal Fuel

Reference: 9

Fuel Rods: 40 in. in length; assembled by stacking hollow fuel slugs in a Type 3S aluminium tube. The slugs were 1·394 in. OD, 0·464 in. ID x 8·00 in. and the aluminium tube 1·500 in. OD, 1·402 in ID.

Lattice Type: Hexagonal

Moderator/Reflector: Water

These experiments were performed with the fuel rods orientated vertically in a 4 ft dia x 5 ft tank of water, the core being reflected on the sides and bottom only.

CORE			DELAYED CRITICAL PARAMETERS		
Lattice Pitch (in.)	Water/U Volume Ratio	H/U^{235} Atomic Ratio	Number of Rods	Core Diameter	Mass
"DRY" SYSTEMS					
2·20	1·79	-	68·7	-	-
2·40	2·37	-	65·7	-	-
SYSTEMS WITH CENTRE OF EACH FUEL ELEMENT FILLED WITH WATER					
2·20	1·91	-	63·0	-	-
2·40	2·50	-	61·4	-	-

Table 10.8

2·70 wt. % Enriched UO_2 Fuel

References: 10, 11

Fuel Rods: Assembled by stacking 0·3 in. OD fuel pellets in a Type 304 stainless steel tube to a length of 48·00 in. (See Figure 10·1)

Lattice Type: Square

Moderator/Reflector: Water

These experiments were performed with the fuel rods orientated vertically in a 6 ft dia x 7 ft stainless steel tank of water, the core cross-section being maintained as nearly circular as possible and the core being reflected on all sides by water. The fuel rods were supported in four matrix plates, themselves supported by a ~ 51 in. OD aluminium core barrel, the top plate being 1 in. thick aluminium, the bottom plate 1½ in. thick aluminium and the two plates spaced equally between ½ in. thick Lucite. Separate sets of plates were available for each lattice pitch.

CORE			DELAYED CRITICAL PARAMETERS			
Lattice Pitch (in.)	Water/U Volume Ratio	H/U^{235} Atomic Ratio	Number of Rods	Core[a] Radius (cm)	Core Height (cm)	U^{235} Mass (kgm)
0·405	2·2	-	3043	32·01	121·9	41·3
0·435	2·9	-	1851	26·82		25·1
0·470	3·9	-	1301	24·27		17·6

a. Calculated on an equal area basis, the cross-sectional area of the core being taken as the product of the unit cell area and the number of unit cells

Table 10.9

3·063 wt % Enriched Metal Fuel

Fuel Rods: Assembled by stacking 8 in. long uranium slugs in 0·031 in. thick walled Lucite tubes. (Subsidiary experiments showed that the Lucite tubes do not affect the results.)

Lattice Type: Hexagonal

Moderator/Reflector: Water

These experiments were performed with the fuel rods orientated vertically in a 4 ft dia x 5 ft tank of water. The core cross-section was maintained as nearly circular as possible and an effectively infinite water reflector is said to have been maintained on all sides of the core, the end reflectors being completed by loading Lucite plugs above and below the uranium in the fuel rods. The fuel rods were supported in an aluminium framework.

CORE			DELAYED CRITICAL PARAMETERS				REFERENCES
Lattice Pitch (in.)	Water/U Volume Ratio	H/U^{235} Atomic Ratio	Number of Rods	Core[a] Diameter (cm)	Core Height (in.)	Uranium Mass (lb)	
0·925 in. dia FUEL RODS							
1·5	1·89	-	72·1	33·96	16	531	12
		-	60·0	31·0	24	663	12
1·6	2·29	-	63·5	34·02	16	468	12
			52·4	30·9	24	579	12
1·7	2·72	-	58·6	34·7	16	431	12
			49·3	31·84	24	544	12
1·8	3·17	-	56·7	36·16	16	418	12
			46·9	32·85	24	518	12
1·95	3·89	-	60·4	40·41	16	445	12
			48·6	36·26	24	537	12
0·600 in. dia FUEL RODS							
1·00	2·06	-	152·1[b]	32·9[b]	16	471[b]	13
1·10	2·71	-	118·6	31·94	16	367	13
1·20	3·41	-	104·5	32·72	16	324	13
1·30	4·18	-	98·9	34·48	16	306	13
1·42	5·18	-	100·3	37·94	16	311	13
1·60	6·84	-	122·0	47·14	16	378	13
0·300 in. dia FUEL RODS							
0·600	3·41	-	387·5	31·5	16	299	14
			-[c]	-[c]	32[c]	460[c]	15
0·700	5·00	-	296·5	32·16	16	229	14
			-[c]	-[c]	32[c]	355[c]	15
0·800	6·84	-	272·3	35·20	16	210	14
			-[c]	-[c]	32[c]	312[c]	15
0·900	8·92	-	285·7	40·58	16	221	14
			-[c]	-[c]	32[c]	315[c]	15
0·175 in. dia FUEL RODS[d]							
0·375	4·06	-	873·26	29·56	23·5	337·1	16
0·450	6·29	-	628·3	30·08	23·5	242·5	16
0·500	8·00	-	569·7	31·84	23·5	219·9	16
0·550	9·89	-	554·2	34·54	23·5	213·9	16
0·600	11·96	-	572·5	38·30	23·5	221·0	16

a. Calculated on an equal area basis, the cross-sectional area of the core being taken as the product of the unit cell area and the number of unit cells

b. 21 outer fuel rods encased in 0·646 in. OD x 0·020 in. thick aluminium tubes

c. About ½ in. aluminium interposed between the core and the bottom water reflector

d. Lucite tubes 0·025 in. thick

Table 10.10

UO_2/ThO_2 Mixture Fuel (93·2 wt. % Enriched Uranium)

Reference: 17

Fuel Rods: Assembled by stacking fuel slugs in a 0·309 in. OD Type 2S aluminium tube. Two types of rod were used:

	1.[a]	2.
Th/U^{235} ATOMIC RATIO	15·00	25·34
CLADDING THICKNESS	0·014 in.	0·034 in.
LENGTH OF FUELLED SECTION	60 in.	60 in.
WEIGHT OF FUEL	356·8 gm	434·6 gm

Lattice Type: Square

Moderator/Reflector: Water

These experiments were performed with the fuel rods orientated vertically in a water tank, maintaining the cross-section of the core as nearly circular as possible. The fuel rods were supported in two 'egg-crate' grids, the lower of which rested on a 4 in. thick aluminium plate on the bottom of the tank and the upper of which was supported at about the 5 ft level by an aluminium structure.

CORE			DELAYED CRITICAL PARAMETERS			
Lattice Pitch (in.)	Water/ (ThO_2+UO_2) Volume Ratio	H/U^{235} Atomic Ratio	Number of Rods	Core Diameter (cm)	Water[b] Height (cm)	U^{235} Mass (kgm)
Th/U^{235} = 25·34 FUEL						
0·4810	3·636	329	1176	47·28	140·5	13·99
0·5694	5·794	528	1118	54·6	181·5	13·46
Th/U^{235} = 15·00 FUEL						
0·3850	1·379	78·0	1108	36·74	127·21	25·96
0·4027	1·642	131	880	34·24	133·44	20·79
0·4810	2·945	165	514	31·26	135·0	9·73

a. 38% of uranium present as U_3O_8

b. Measured from the lower end of the fuel rods 1·9 cm below the fuelled section

EXPERIMENTAL RESULTS FOR U^{235} FUELLED LATTICES WITH MIXED DEUTERIUM/HYDROGEN MODERATION

Table 10.11

UO_2 Fuel

Reference: 18

Fuel Rods: Assembled by stacking fuel slugs in a stainless steel or aluminium tube. Two types of rod were used:

	1.	2.
URANIUM ENRICHMENT (wt %)	2·459	4·020
O.D.	0·4748 in.	0·4755 in.
CLADDING	ASTM Type 6061 aluminium	Type 304 stainless steel
LENGTH OF FUELLED SECTION	60·37 in.	56·7 in.
TOTAL LENGTH	61·59 in.	~71·5 in.
WEIGHT OF FUEL	1306 gm.	1600 gm.
FUEL PELLET DIA.	0·4054 in.	0·444 in.
URANIUM CONTENT OF FUEL	88·13 wt %	88·01 wt %

The end caps of the 4·020% enriched rods were inverted stainless steel thimbles filled with aluminium or stainless steel. The end caps of the 2·459% enriched rods were ½ in. thick aluminium and had a 1 in. long dead-space at the top.

Lattice Type: Square

Moderator/ Reflector: Mixed light and heavy water

These experiments were performed with the fuel rods orientated vertically in a 5 ft dia x 6·5 ft tank of water mounted inside a second 9 ft dia tank. The core cross-section was maintained as nearly circular as possible. The fuel rods were supported in top, midplane and bottom matrix plates and rested on a 2 in. thick aluminium base plate on the bottom of the tank. The upper and lower matrix plates were of the 'egg-crate' type fabricated from 1 in. wide aluminium strip. The midplane plate was of $\frac{1}{16}$ in. thick drilled aluminium and subsidiary experiments showed that it had only negligible reactivity worth.

CORE				DELAYED CRITICAL PARAMETERS			
Lattice Pitch (in.)	Total Non-moderator / Total Moderator Volume Ratio	Mol % D_2O in Moderator / Reflector	Radial Reflector Thickness (cm)	Number of Rods	Core[a] Radius (cm)	Moderator Height (Above Lower End of Fuelled Section of Rods) (cm)	Mass
2·459 wt % Enriched Fuel Rods							
0·595	1·001	0·0	55·38	596	20·82	141·1	-
		70·0	30·73	2852	45·47	134·9	-
		49·8	47·41	1140	28·79	134·5	-
0·670	0·651	85·5	7·47	5124	68·73	134·2	-
		70·0	47·85	872	28·35	134·7	-
4·02 wt % Enriched Fuel Rods							
0·595	1·006	0·0	eff. inf.(c)	484(b)	18·75(b)	159·0(b)	-
		76·5	14·22 (d)	5284	61·98	152·9	-
		69·7	35·74	2252	40·46	151·0	-
		49·7	49·89	952	26·31	150·6	-
0·571	1·195	0·0	56·02	608	20·18	146·1	-
		70·1	16·52	5320	59·68	146·1	-
		49·7	45·69	1390	30·51	146·1	-

a. Calculated on an equal area basis, the cross-sectional area of the core being taken as the product of the unit cell area and the number of unit cells

b. Upper and lower matrix plates replaced by ½ in. thick drilled stainless steel plates. Midplane matrix plate of ½ in. thick drilled Lucite

c. Experiment performed in 9 ft dia tank

d. In this experiment an additional 5 in. thickness of paraffin was placed round the outside of the radial surface of the 5 ft dia tank.

Table 10.12

1·824 wt % Plutonium/Aluminium[a] Alloy Fuel

Reference: 19

Fuel Rods: 0·500 in. dia x 44 in.; containing an average of 7·12 gm plutonium per rod and clad in 0·030 in. thick zircalloy 2, 0·566 in. OD. One end of each rod contained helium in a 0·400 in. long region between the fuel and the end cap. The weights of the end caps and the section of tubing beyond the fuel averaged 12·4 gm at one end and 21·6 gm at the other end. Pu^{240} content of plutonium varied but was principally 5·05 or 6·00 wt % with an average value of 5·58 wt %. The distribution of rods with differing Pu^{240} contents was random throughout the lattice. Al/Pu atomic ratio - ; Zr/Pu atomic ratio -

Lattice Type: Hexagonal

Moderator/Reflector: Water

These experiments were performed with the fuel rods orientated vertically in a 4 ft dia x 5 ft tank of water. The core cross-section was hexagonal and an effectively infinite thickness of water is said to have been maintained on all sides of the core. The rods were supported in matrix plates fabricated in Lucite except for the top plate which was of ¼ in. thick aluminium and was positioned 2 ins. above the end of the fuelled sections of the rods. Each rod was enclosed in a 0·032 in. thick Lucite tube, 0·650 in. OD, the space between the rod and the tube being filled with water to minimise voids. Subsidiary experiments showed that the Lucite tubes do not affect the results.

CORE			DELAYED CRITICAL PARAMETERS		
Lattice Pitch (in.)	H_2O/Rod Volume Ratio	H/Pu Atomic Ratio	Number of Rods	Core Diameter	Plutonium Mass (kgm)
0·75	0·9361	630	563·4	-	4·01
0·80	1·203	810	510·3	-	3·63
0·85	1·487	1001	493·9	-	3·52
0·90	1·788	1204	515·8	-	3·67
0·95	2·106	1418	577·7	-	4·11

a. Average composition: 97·21 wt % Al, 1·61 wt % Ni, 0·69 wt % Si, 0·49 wt % Fe

Table 10.13

2·006 wt% Plutonium/Aluminium[a] Alloy Fuel

Reference: 20

Fuel Rods: 0·500 in. dia x 36 in. containing an average of 6·383 gm plutonium per rod and clad in 0·03 in. thick Zircaloy 2, 0·566 in. O.D. Total Zircaloy per rod 207·8 gm, of which 6·0 gm and 6·5 gm respectively constituted lower and upper end caps.

Average isotopic composition of plutonium 81·01% Pu^{239}, 16·46% Pu^{240}, 2·31% Pu^{241}, 0·20% Pu^{242}.
Al/Pu atomic ratio - Zr/Pu atomic ratio -.

Lattice Type: Hexagonal

Moderator/Reflector: Water

These experiments were performed with the fuel rods orientated vertically in a 4 ft dia x 5 ft tank of water. The core cross-section was hexagonal and an effectively infinite thickness of water is said to have been maintained on all sides of the cores. The rods were supported in matrix plates fabricated in Lucite except for the top plate which was of $\frac{1}{4}$ in. thick aluminium and was positioned 1 in. below the ends of the fuelled sections of the rods. Each rod was enclosed in a 0·032 in. thick Lucite tube, 0·650 in. O.D. the space between the rod and the tube being filled with water to minimise voids. Subsidiary experiments showed that the Lucite tubes do not affect the results.

CORE			DELAYED CRITICAL PARAMETERS		
Lattice Pitch (in.)	H_2O/Rod Volume Ratio	H/Pu Atomic Ratio	Number of Rods	Core Diameter	Plutonium Mass (kgm)
0·66[b]	0·4993	308·4	138·3	-	8·828
0·75	0·9360	578·1	848·4	-	5·415
0·80	1·202	742·7	795·6	-	5·078
0·85	1·487	918·2	785·6	-	5·014
0·90	1·788	1104	869·8	-	5·552
0·95	2·106	1301	1099·2	-	7·016

a. Average composition, 97·57 wt% Al, 1·63 wt% Ni, 0·4 wt% Fe, 0·3 wt% Si, 0·1 wt% Cu

b. These rods were not enclosed in Lucite tubes

Table 10.14

5 wt. % Plutonium/Aluminium Alloy Fuel

Reference. 21, 22

Fuel Rods: 0·506 in. dia x 24 in; containing an average of 11·01 gm plutonium per rod and clad in 0·03 in. thick Zircalloy 2 with 0·020 and 0·125 in. thick end caps.
Pu^{240} content of plutonium 5·0 wt. %.
Al/Pu atomic ratio = 168·20, Zr/Pu atomic ratio = 31·92.

Lattice Type: Hexagonal

Moderator/Reflector: Water

These experiments were performed with the fuel rods orientated vertically in a 4 ft dia x 5 ft tank of water. The core cross-section was hexagonal and an effectively infinite thickness of water is said to have been maintained on all sides of the core. The rods were supported in Lucite matrix plates.

CORE			DELAYED CRITICAL PARAMETERS		
Lattice Pitch (in.)	H_2O/Rod Volume Ratio	H/Pu Atomic Ratio	Number of Rods	Core Diameter	Plutonium Mass (kgm)
0·85	1·86	354·7	230·2	-	2·54
0·90	2·23	426·8	192·0	-	2·11
1·00	3·06	582·6	170·1	-	1·87
1·10	3·96	755·1	166·5	-	1·88
1·20	4·95	944·0	181·1	-	1·99
1·30	6·03	1149·3	215·5	-	2·37

FUEL ROD DIMENSIONS

FUEL	
URANIUM CONTENT	88·7%
UO_2 CONTENT	99·2%
ENRICHMENT	2·700 ± 0·017 wt%
FORM	SINTERED UO_2 PELLETS
PELLETS/ROD	80
DIAMETER	0·3000 ± 0·0002 in
LENGTH/PELLET	0·5989 ± 0·0034 in
LENGTH/ROD	48·00 ± 0·15 in
DENSITY/PELLET	10·2 ± 0·1 gm/cm^3
WEIGHT/PELLET	7·07 ± 0·13 gm.
WEIGHT/ROD	566·0 ± 4 6gm.

CLADDING	
TYPE	304 STAINLESS STEEL
TUBING :	
INSIDE DIAMETER	0·3062 ± 0·0009"
WALL THICKNESS	0·0161 ± 0·0003"
LENGTH	49·420 ± 0·007"
WEIGHT	104·5 ± 1·4 gm
END PLUGS	304 STAINLESS STEEL

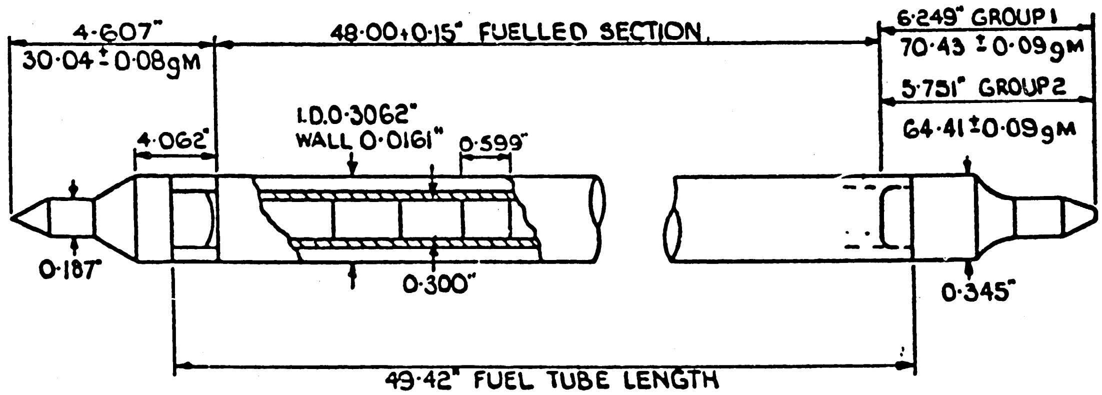


FIGURE 10·1 (SEE TABLE 10·8)